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Volume I. Summary Report

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The Jamaica Bay ecosystem and wastewater discharges to the bay were characterized during a comprehensive 3-year study. The primary objective of the project was the development of management criteria and procedures for the bay ecosystem, with major emphasis on combined sewer overflow management to provide for water contact recreation in the bay. Analysis of the sampling results and the output of the hydrologic models developed during the project demonstrated that (1) the four municipal sewage treatment facility effluents are the major sources of organic and nutrient materials discharged to the bay; (2) combined sewer overflows represent significant sources of solids and coliforms to the bay; (3) the Spring Creek combined sewer overflow treatment facility will provide substantial benefit in reducing overall pollution from combined sewer overflows in the Jamaica Bay drainage basin, and (4) treatment of combined sewer overflows from the Paerdegat Basin will provide the next greatest benefit to the quality of the bay. Recommendations are presented on the most cost-effective development of a wastewater management program for the Jamaica Bay drainage basin that would result in water quality conditions suitable for water contact recreation at all potential beaches along the perimeter of Jamaica Bay.

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WASTEWATER MANAGEMENT PROGRAM
JAMAICA BAY, NEW YORK

Volume I
Summary Report

by

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FOREWORD

The Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimony to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution and it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems for the prevention, treatment, and management of wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, for the preservation and treatment of public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research; a most vital communications link between the researcher and the user community.

This particular effort demonstrated the cost-effectiveness of a wastewater management program, incorporating improved treatment of municipal sewage and control and treatment of combined sewer overflows, that would achieve bathing water quality throughout a major recreational resource adjacent to the largest population center in the United States.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory

ABSTRACT

The Jamaica Bay ecosystem and wastewater discharges to the bay were characterized during a comprehensive 3-year study. The primary objective of the project was the development of management criteria and procedures for the bay ecosystem, with major emphasis on combined sewer overflow management to provide for water contact recreation in the bay.

Jamaica Bay was created by marsh dredging and retains may marshland characteristics. Thus, management of the bay ecosystem for long-term beneficial uses will require control of the impacts of man's activities in the surrounding environs.

Analysis of the sampling results and the output of the hydrologic models developed during the project demonstrated that (1) the four municipal sewage treatment facility effluents are the major sources of organic and nutrient materials discharged to the bay, (2) combined sewer overflows represent significant sources of solids and coliforms to the bay, (3) the Spring Creek combined sewer overflow treatment facility will provide substantial benefit in reducing overall pollution from combined sewer overflows in the Jamaica Bay drainage basin and (4) treatment of combined sewer overflows from the Paerdegat Basin will provide the next greatest benefit to the quality of the bay.

The estimated capital cost of upgrading the four sewage treatment facilities is $185,183,000 and the estimated capital cost of providing treatment for all combined sewer overflows is $123,272,000 (1973 dollars). Recommendations are presented on the most cost-effective development of a wastewater management program for the Jamaica Bay drainage basin.

Implementation of these recommendations would result in water quality conditions suitable for water contact recreation at all potential beaches along the perimeter of Jamaica Bay.

Volume II of this report contains supplemental data on the water quality and sediment quality of Jamaica Bay. It is available from the National Technical Information Service.

Department of Commerce
Springfield, Virginia 22161

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SECTION I

CONCLUSIONS

Achievement of bathing water standards at all times during the summer recreational season at potential beach sites is one of the primary water quality objectives for Jamaica Bay. This will require disinfection of all combined sewer overflows to the bay. Improvement in the quality of the ecosystem, the other primary objective, will require upgrading of the performance of the four major sewage treatment facilities that discharge to the bay.

The wastewater management improvement program initiated several years ago by the Department of Water Resources, City of New York, will, upon its completion, result in lowering of the bacterial levels in Jamaica Bay to bathing water standards at all times at potential beach sites during the recreational season and in substantial improvement in the quality of the ecosystem at all times of the year. Key elements of the program are the performance upgrading of the four existing water pollution control facilities to effect greater removals of suspended solids and organic, oxygen-demanding materials and the phased construction of treatment facilities on the eight major combined sewer overflows to effect, primarily, substantial reduction in bacterial densities. At the present time, three municipal sewage treatment facilities (26th Ward, Jamaica and Rockaway) are being modified to full step-aeration processes and one auxiliary facility (Spring Creek) has been completed to capture and treat the combined sewer overflows from two of the basins (Spring Creek East and Spring Creek West).

Performance upgrading of all four sewage treatment facilities will result in substantial reductions of average total pollutant loadings of oxygen-demanding substances and suspended solids, in addition to lesser reductions in other pollutants such as nutrients and oil and grease. However, little effect upon the improvement of bacterial quality and hence compliance with bathing water standards will be realized unless combined sewer overflows are disinfected.

Reduction in the average levels of oxygen-demanding materials to near natural background levels in the bay can be accomplished only by routing nearly all of the dry- and wet-weather sewage treatment facility effluents and combined sewer overflows out of the bay to the New York Bight. Because the levels of oxygen-demanding materials in the bay that will result from the discharges of the upgraded treatment facilities are not believed to present serious problems in the ecosystem, the relative high cost of routing the wastewaters out of the bay to further reduce these levels does not appear justified.

WASTEWATER INFLOWS

Jamaica Bay presently receives numerous inflows along its periphery, including treated municipal wastewaters, surface runoff from separately sewered areas, combined sewer overflows and other minor pollutant sources. Data characterizing these inflows were obtained during the conduct of this project and were used to assess their impact upon Jamaica Bay under various alternative wastewater management programs.

Major conclusions concerning the wastewater characteristics and the importance of the inflows to the bay are presented below.

1. The proportion of rainfall on combined sewered areas that results in combined sewer overflows varies from 38% in the Thurston Basin drainage area to over 92% in the Hendrix Creek drainage area. These variations are attributed to differences in upstream storage capacities in the various sewer systems.

2. Discharge to the bay from the Spring Creek combined sewer overflow treatment facility occurs for about one-fourth of the 40 storms typically occurring during the 5-month (mo) summer recreational season.

3. Average per capita municipal wastewater flow and pollutant loadings are typical of other urban areas; i.e.,

Flow	162 gallons per day (gpd)
Biochemical oxygen demand (BOD_5)	0.160 pounds per day (lb/day)
Chemical oxygen demand (COD)	0.525 lb/day
Suspended solids (SS)	0.194 lb/day
Hexane extractable materials (HEM)	0.032 lb/day
Total nitrogen (TN)	0.059 lb/day
Total inorganic nitrogen (TIN)	0.023 lb/day
Total organic nitrogen (TON)	0.035 lb/day
Total phosphorus (TP)	0.012 lb/day
Total soluble phosphorus (TSP)	0.008 lb/day

4. Average 5-day, 20°C biochemical oxygen demand (BOD_5) removal efficiencies for the four sewage treatment facilities (26th Ward, Coney Island, Jamaica and Rockaway) prior to their upgrading (1970) ranged from 55 to 63%. This corresponds to an intermediate (between primary and secondary) level of treatment.

5. Following upgrading of the four existing sewage treatment facilities to full step-aeration processes, they are expected to remove from 85 to 90% of the BOD_5, which will constitute a secondary level of treatment.

6. The overall bacterial quality of the sewage treatment facility effluents will be greatly improved following upgrading of the

chlorination facilities at the 26th Ward facility. Chlorination facilities at the other three sewage treatment facilities are adequate.

7. Mass emission coefficients, expressed as pounds per acre, of 7 pollutants in the 44 storms monitored during this project correlated linearly with storm overflow depth. The pollutants are BOD_5, COD, SS, HEM, TON, TIN and TSP.

8. The urban runoff model developed in this project is an extremely useful tool for predicting the total amount and time history of pollutants, such as BOD and total coliforms, discharged to Jamaica Bay as a result of a combined sewer overflow. The appropriate equation is:

$$C_t = \left[\frac{C_D\, q_D}{q_D + q_S}\right]_t + \alpha S(q_S + q_D)_t^{n-1} + W(q_S)_t^{k-1}$$

where C_t = constituent concentration at time t;

C_D = dry-weather constituent concentration;

q_D = dry-weather flow rate;

q_S = wet-weather flow rate;

S = coefficient related to storage factor and sewer slope;

$\alpha = 0$ when $t > t_{max}$ or

$\alpha = 1$ when $t \leq t_{max}$;

t_{max} = time of hydrograph peak;

n = empirical coefficient;

W = coefficient varying with street cleaning frequency, basin geometry and population density; and

k = varies from 1.5 to 2.0.

9. The time history of total coliforms contained in a combined sewer overflow was found to follow a W-shaped curve. The shape results from a combination of the three components of the runoff model. The first component accounts for dilution of dry-weather coliform concentrations by stormwater runoff. The second component accounts for the addition of coliforms from scoured sediments in the sewer. The third component accounts for the contribution of coliforms from street gutters. The central peak in the concentration profile, creating the W-shaped curve, is caused by the scouring component, which rises exponentially as the storm hydrograph rises but drops sharply as the sediments are resuspended.

10. The performance of the Spring Creek combined sewer overflow treatment facility will vary according to transient storm character-

istics, ranging from a secondary level of treatment when all runoff to the facility can be totally contained and subsequently drained to the 26th Ward treatment facility to a decreasing level of treatment commensurate with sedimentation basin performance characteristics for increasing storm sizes.

11. Prior to upgrading of the four sewage treatment facilities and prior to control of any combined sewer overflows, the relative contributions of BOD_5 to Jamaica Bay from the various sources was 81% for sewage treatment plants, 14% for combined sewer overflows, 4% for separate storm sewers and < 1% for all other sources. Following upgrading of the four sewage treatment facilities and if all combined sewer overflows are treated by facilities comparable to the Spring Creek facility, the relative contributions of BOD_5 would be 76% for sewage treatment plants, 14% for combined sewer overflows, 10% for separate storm sewers and < 1% for all other sources.

12. The four sewage treatment facilities prior to upgrading contribute over 90% of the nutrient loading to Jamaica Bay. Because of the small contribution from other sources, and negligible effect of the improved processes on nutrient removal, these facilities will continue to contribute over 90% of the nutrient loading after upgrading.

13. As a result of upgrading the four sewage treatment facilities to step aeration, the total annual average pollutant loadings to Jamaica Bay from all sources of BOD_5 will decrease 60%, COD will decrease 23%, total suspended solids will decrease 38%, HEM will decrease 29%, total nitrogen will increase 2% and total phosphorus will decrease 7%. (The increase in nitrogen is due to increased future flows at the sewage treatment facilities and low removal rates.)

RECEIVING WATER QUALITY

From the extensive water quality data base established as part of this project, the following conclusions have been drawn regarding the characteristics of Jamaica Bay, particularly in the way the bay has been modified by waste discharges.

14. Very little net circulation occurs in Jamaica Bay. Nearly all water that enters the bay on flooding tide leaves the bay on ebbing tide. The net advective daily flow out of the bay is equivalent to < 1% of the volume of the bay.

15. The extensive tide-induced movements of water in Jamaica Bay create sufficient turbulence to cause nearly completely mixed conditions in the vertical dimension in most areas of the bay. The only exception is the Grassy Bay area which exhibits some stratification.

16. During the summer a gradient of increasing temperature exists

from Rockaway Inlet to Head of Bay. This is due primarily to ambient air temperatures having a more pronounced effect on the shallower bay waters than on the deeper portions.

17. Water transparency of Jamaica Bay is lower in the summer than in the winter. Summertime averages ranged from 0.6 to 1.6 meters (m), whereas wintertime averages ranged between 1.2 and 2.4 m.

18. Significant differences in summertime and wintertime average total suspended solids concentrations occur only in the mid-bay channels, where values decreased from 53 milligrams per liter (mg/l) in the summer to 19 mg/l in the winter. Elsewhere throughout the bay, average values were in the order of 8 and 10 mg/l.

19. Volatile suspended solids concentrations in Jamaica Bay are similar in the summer and the winter except in the center of the bay due to the proximity of the marshland areas, where the summertime average was about 12 mg/l as compared to the wintertime average of around 6 mg/l.

20. The pH of Jamaica Bay waters is lower in the summer than the winter, probably due to higher algal photosynthetic activity in the winter which causes a decrease in water acidity. The lowest average pH in the summer was 7.4, whereas the lowest in the winter was 7.8.

21. A small chlorosity gradient exists in the bay during both seasons. Chlorosities in the Grassy Bay area are approximately 18% below that found in the New York Bight. This slight gradient is caused by the relatively small amount of fresh water (< 1% of the volume of the bay each day) that is discharged to the bay.

22. Dissolved oxygen levels in Jamaica Bay are higher everywhere during the winter as compared to the summer due to temperature-induced differences in the saturation and the reduction in the rate of BOD exertion during the winter. Average dissolved oxygen levels ranged from about 3 to 7 mg/l during the summer and from about 10 to 13 mg/l in the winter.

23. Due to poor water circulation and proximity of wastewater discharges in the Grassy Bay area, dissolved oxygen levels during the summer in this area are depressed to about 24% of saturation levels, as contrasted to relatively high levels extant elsewhere throughout the bay. During the winter, all of the bay is saturated or nearly saturated with oxygen.

24. The seasonal differences in BOD_5 concentrations in Jamaica Bay waters are the result of seasonal metabolic differences. BOD_5 concentrations are higher in the vicinities of the 26th Ward and Jamaica sewage treatment facility discharges and in the center of the bay, due to effluents and marsh grass decomposition, respectively. Summertime averages of BOD_5 ranged from about 2.0 to 3.5 mg/l; whereas

wintertime averages ranged from about 2.5 to 5.0 mg/l.

25. Average organic nitrogen, ammonia and nitrate concentrations in Jamaica Bay waters are highest in the Grassy Bay area due to poor water circulation and the proximity of the water pollution control facility effluents, which are the primary sources of this material.

26. The amounts of nitrogen in Jamaica Bay waters are sufficient to support large populations of algae.

27. Total phosphate and orthophosphate concentrations in the waters are highest in the back-bay areas of the bay due to the proximity of the sewage treatment facility discharges and poor water circulation in these areas.

28. Except for localized areas of Jamaica Bay, most concentrations of HEM in the waters are about equal in summer and winter. A wintertime average HEM of 3.4 mg/l was noted near the John F. Kennedy International Airport; the same area indicated an average summertime concentration of only 0.5 mg/l.

29. Total coliform, fecal coliform and fecal streptococci densities in the waters of Jamaica Bay are higher in the winter than in the summer. This is due to the practice of not chlorinating effluents from the sewage treatment facilities during the winter. Concentrations of total coliforms in excess of bathing water standards were observed throughout the north channel during the summer and throughout the bay during the winter. Coliform disappearance studies showed that, because of the low rate of measured die-away, the frequent occurrence of combined sewer overflows would be sufficient to maintain concentrations in the bay waters at these high levels.

30. Microplankton concentrations in Jamaica Bay are much higher in the winter than in the summer. Although there appeared to be no correlation between concentration of microplankton and location of wastewater discharges, the microplankton diversity index shows marked reduction in areas near combined sewer overflows, particularly Paerdegat Basin, Fresh Creek Basin and Bergen Basin.

31. Average zooplankton concentrations in Jamaica Bay in the winter were an order of magnitude less than summertime averages. Neither summer nor winter zooplankton populations appeared to correlate with sewage treatment facility discharge or combined sewer overflow locations. Zooplankton species diversity indices were somewhat lower in the north channel in the proximity of the 26th Ward facility discharge.

32. Special samplings in other bays on Long Island indicated that water quality, as measured by BOD_5, soluble phosphorus, total coliforms, microplankton and zooplankton concentrations, is presently lower in

Jamaica Bay than in other Long Island bays. This reflects the effects of wastewater discharges to Jamaica Bay. Results of fish and invertebrate trawls in Jamaica Bay and other Long Island bays showed that a more balanced and favorable fish and invertebrate community exists in Jamaica Bay, however, than in the other Long Island bays.

33. Sediment quality of Jamaica Bay did not show seasonal variations. Quality was found to be degraded in the back part of the bay due to poor water circulation which allows settleable solids to accumulate. For example, sediment BOD_5 was highest in the Head of Bay area, and the highest values of HEM, sulfides and phosphorus occurred in the Grassy Bay area.

34. The distribution of benthos reflected the spatial distribution of degraded sediment conditions. Minimum species diversity indices of less than 0.2 were observed in the Grassy Bay area.

35. The quality of Jamaica Bay sediments is higher than for other Long Island bays due to continuous dredging to maintain navigable waterways in the bay.

36. Heavy metals are accumulating in Jamaica Bay, but their present levels are not high enough to cause acute toxicity to marine organisms. Average concentrations, expressed as micrograms per liter (μg/l), were 100 for copper, 1.5 for chromium, 15 for nickel, 120 for zinc, 2.9 for cadmium, 120 for lead and 2.9 for mercury.

37. The results of analyses for chlorinated hydrocarbons in the waters and sediments of Jamaica Bay show a gradual increase from Rockaway Inlet to the east end of the bay. Although concentrations of total chlorinated hydrocarbons in the sediments are several orders of magnitude greater than those found in the waters, there is no evidence that these levels, or levels in the overlying waters, are obstacles to development of additional beneficial uses for Jamaica Bay.

WASTEWATER TREATMENT

The following conclusions can be drawn from the planned upgrading of the four existing dry-weather sewage treatment facilities.

38. Upgrading of the 26th Ward, Coney Island, Jamaica and Rockaway facilities to provide secondary (step-aeration) treatment and improvement of the chlorination facilities at the 26th Ward facility to a total ultimate capacity of 340 million gallons per day (mgd) will require a total estimated capital cost of $185,183,000. Including the estimated costs for additional operation and maintenance of upgraded facilities, the total annual cost would be $18,272,000.

39. Improving the chlorination facilities at the 26th Ward facility will increase the total number of usable beach days in

Jamaica Bay by only 1%. Greater increases would be noticeable, however, at potential bathing beach sites located at Canarsie Beach, between Canarsie Beach and Fresh Creek and between Spring Creek and Shellbank Basin.

40. Upgrading the four sewage treatment facilities to the step-aeration process will reduce the average BOD_5 concentrations in Jamaica Bay by approximately 33% from that prior to construction and operation of the Spring Creek combined sewer overflow treatment facility, thereby increasing the dissolved oxygen levels in the bay. Improvement will be higher in areas near the discharge locations of the four sewage treatment facilities.

COST-EFFECTIVENESS

Analysis of the cost-effectiveness of each individual combined sewer overflow treatment facility and alternative combinations of two or more facilities in conjunction with the upgraded sewage treatment facilities has led to the following conclusions.

41. The Spring Creek auxiliary facility, recently completed at a cost of $14,300,000, should show an overall 8% improvement in the usable beach days in Jamaica Bay and a 12% improvement in the usable beach days at the potential beach between Spring Creek and Shellbank Basin. A small decrease in the average concentrations of BOD and other wastewater constituents in Jamaica Bay will be associated with the operation of the Spring Creek facility.

42. Capital costs for combined sewer overflow treatment at proposed locations range from $4,991,000 at Hendrix Creek Basin to $39,007,000 at Thurston Basin. The difference in cost is due in part to the difference in size between each treatment facility and in part to the extent of the interceptors that must be constructed to divert the combined sewer overflows to the facility.

43. The effect of untreated combined sewer overflow on the potential beaches in Jamaica Bay depends upon the size of the drainage area, the size of the storm, the tidal conditions during and after the rainfall and the proximity to potential beach sites.

44. Development of Canarsie Beach and a beach site between Canarsie Beach and Fresh Creek adjacent to Floyd Bennett Field and Island Channel into a totally usable beach will require management of the Fresh Creek Basin and Paerdegat Basin combined sewer overflows.

45. Development of potential beach sites at Canarsie Beach and between Canarsie Beach and Fresh Creek into totally usable beaches will require management of the Paerdegat Basin, Fresh Creek Basin, Hendrix Creek Basin and Spring Creek Basin combined sewer overflows.

46. Development of a beach site between Spring Creek and Shellbank Basin into a totally usable beach will require management of the Fresh Creek Basin, Hendrix Creek Basin, Spring Creek Basin and Bergen Basin combined sewer overflows.

47. The most cost-effective addition to the upgraded sewage treatment facilities and the Spring Creek combined sewer overflow facility would be to construct an auxiliary facility to serve the Paerdegat Basin.

48. Construction of all potential combined sewer overflow treatment facilities will enable water quality in Jamaica Bay to always meet the water quality standards for total coliform density at all potential beach sites.

49. It is estimated that a total capital cost of $308,455,000 and a total annual cost of $29,402,000 will be required to upgrade the four sewage treatment facilities and provide an auxiliary facility for each major combined sewer overflow to Jamaica Bay.

50. Although a submarine outfall system could also provide totally usable beaches within Jamaica Bay and even further reductions in BOD and other constituent concentrations within the bay, such a system is not cost-effective. The capital cost for a system to provide total protection to potential beach sites is estimated to be $569,483,000, and an annual cost of $53,134,000. These costs are much higher than wastewater management programs involving combined sewer overflow control and treatment.

SECTION II

RECOMMENDATIONS

The results of this project have led to the following recommendations regarding wastewater management in the Jamaica Bay drainage area.

1. The sewage treatment facility performance upgrading program should be given the highest priority for implementation.

2. Design of future auxiliary facilities for treatment of combined sewer overflows should proceed only after the performance and effects of preceding facilities have been carefully assessed.

3. With regard to construction of additional auxiliary facilities, the highest priority should be assigned to Paerdegat Basin and Fresh Creek Basin.

4. To provide totally usable beaches from the standpoint of bacterial quality, steps should be taken to construct auxiliary facilities to service each combined sewer overflow to Jamaica Bay.

5. Development of a detailed monitoring program to evaluate the effectiveness of the wastewater management program in improving the quality of Jamaica Bay should await the final development of the Water Quality Simulation Model by the New York City Rand Institute. In this way, key parameters and measurement frequencies can be identified more meaningfully and more economical programs can be designed.

6. The assumed performance capability of the Spring Creek auxiliary facility should be verified.

7. The cost-effectiveness of providing additional storage volume at proposed auxiliary facilities should be studied using the Rand model.

8. The urban runoff model and the Rand model should be used to develop operating criteria for proposed auxiliary facilities.

SECTION III

INTRODUCTION

Jamaica Bay is in many respects quite similar to the other bay systems which span the south shore of Long Island. It is shallow, supports an extensive system of tidal marshes and has a restricted interchange of water with the ocean through a narrow inlet. The bay measures about 4 by 6 miles (mi), and the area encompasses approximately 20 mi^2. Nearly 31% of this area is taken up by islands and tidal marshes in the central portion of the bay.

Jamaica Bay, except for some small reaches in the eastern end, lies entirely within the City of New York. As shown in Figure 1, the bay is bounded on the south by the rather narrow Rockaway Peninsula, which separates it from the New York Bight of the Atlantic Ocean, on the east by Nassau County and the John F. Kennedy International Airport, on the north by the Howard Beach section of the Borough of Queens and on the west by the Borough of Brooklyn.

Although Jamaica Bay covers a rather extensive area, its mean depth is only 16 feet (ft). Because the mean tidal range at Rockaway Inlet is approximately 5 ft and tidal variations within the bay itself are of a similar magnitude, approximately one-third of the volume of the water in the bay flows out through Rockaway Inlet with the ebbing tide and returns on the flooding tide.

Relative to the volume of tidal inflow and outflow from the bay, the net fresh water input to the bay is extremely small, amounting to less than 1% of the volume of the bay on a daily basis. Of the total fresh water input to the bay, sewage treatment facility effluents contribute approximately 70%, or 220 mgd. The remaining 30% is almost equally divided in quantity between combined sewer overflows and storm runoff.

PROBLEM DELINEATION

General Problem

Jamaica Bay, like many other bodies of water in close proximity to urban areas, has been subjected to unplanned and conflicting uses. Furthermore, concepts of water quality requirements have undergone continuous evaluation with time, so that systems for drainage and wastewater treatment instituted in the past no longer conform to contemporary water resource management objectives. In many cases drainage systems date from a time when sewage treatment was considered to be unnecessary or economically infeasible. Sewerage systems were instituted solely for purposes of conveying any and all liquid wastes to points of convenient discharge. When sewage treatment was instituted to improve the quality of the aquatic environment, the existing combined sewer systems

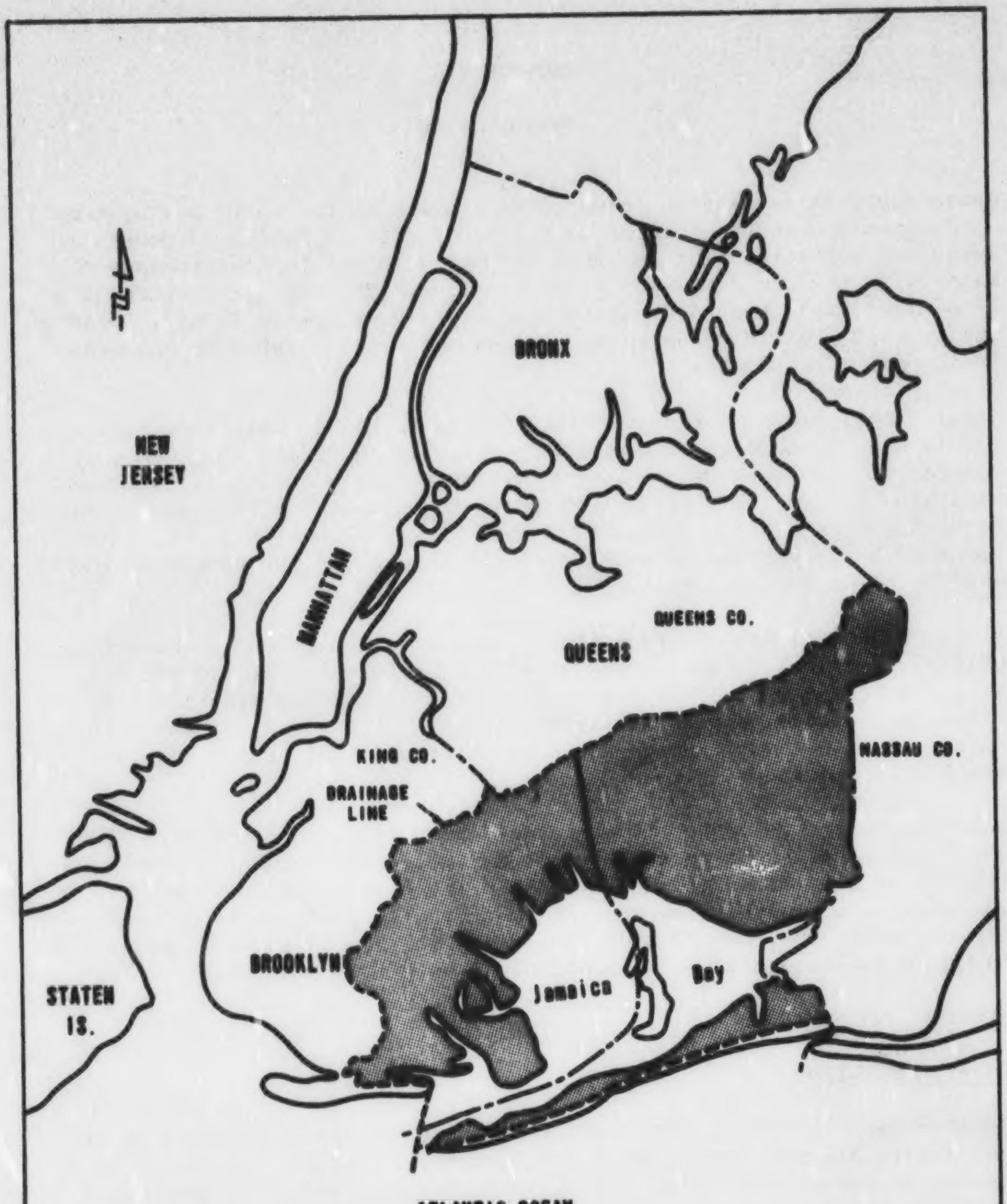

NEW JERSEY
MANHATTAN
BRONX
QUEENS CO.
QUEENS
KING CO.
DRAINAGE LINE
NASSAU CO.
BROOKLYN
STATEN IS.
Jamaica
Bay
ATLANTIC OCEAN

Figure 1. Location map of Jamaica Bay

were retained for economic reasons. As a consequence, during most periods of rainfall, these systems carry more wastewater than can be accommodated by the water pollution control facilities, and the excess flows (consisting of a mixture of sanitary sewage and urban surface runoff) are diverted directly to the receiving water. In this regard, the City of New York is not unique; approximately one-half the United States urban population is served by combined sewers.

To alleviate these problems the city has planned a construction program to control the adverse effects of discharges from combined sewers. Special studies already conducted by the city have shown that the cost of this program will most likely approach $500 million. Consequently, it is the desire of the city that the best possible understanding of the problem be achieved, so that a maximum improvement in the receiving waters can be attained at a minimum cost. With this thought in mind, the Jamaica Bay Wastewater Management Program was initiated.

Specific Problems in Jamaica Bay

Because of the proximity of Jamaica Bay to a heavily urbanized area, its uses have multiplied in number and extent, so that the task of resource allocation has become increasingly difficult. Over the years there has been an increasing awareness of water quality problems, resulting in more stringent water quality requirements for each of the bay uses. Furthermore, the effects of many uses, such as collection of wastewater discharges, conflict with the requirements of other uses, such as recreation and fishing.

Presently the major uses of the bay resources are fishing, boating, wildlife management, dredging for fill material, solid and liquid waste disposal, land reclamation, airport facilities and shipping. Additional uses, which have been seriously restricted or eliminated entirely, include aesthetic enjoyment, primary water contact sports and shellfish propagation.

Many factors contribute to the past and continuing degradation of water quality in Jamaica Bay. Factors with an extensive impact on water quality are those related to the discharge of wastewaters. Effluents discharged from sewage treatment facilities and combined sewer overflows are the most significant wastewaters, although urban surface runoff (storm drainage), drainage from John F. Kennedy International Airport and other miscellaneous sources of wastewaters have a measurable impact on water quality.

Wastewaters are not the only sources contributing to the problem. Drainage from solid waste disposal areas adds pollutants to the bay. Land reclamation has virtually eliminated the productive marsh areas that once surrounded the bay. Dredging, by altering the hydrography and bottom composition, has often resulted in undesirable conditions.

In developing a long-range plan for water pollution control in Jamaica Bay, it was necessary to consider the relative impacts of all these factors.

PROJECT OBJECTIVES

The overall objective of the Jamaica Bay Wastewater Management Program was to determine the feasibility of progressing with a combined sewer overflow control program by evaluating the impact of constructing and operating a combined sewer overflow treatment facility on the Spring Creek drainage basin. The program had as its general objectives:

1. A characterization and evaluation of those parameters that measure the effects of combined sewer overflows and other interacting wastewater discharges;

2. A study of the pre-conditions in the area that would be affected by discharges from the Spring Creek facilities; and

3. The conduct of a post-construction survey to determine the effectiveness of the treatment process in upgrading the quality of the receiving water.

Specific objectives of the completed program phases were:

1. To determine the characteristics of combined sewer overflows and other interacting pollution sources in the bay;

2. To estimate the relative contribution of pollutants by each waste source;

3. To determine the significant physical, chemical and biological characteristics of the waters and sediments of the bay; and

4. To achieve an understanding, insofar as possible, of the effects of waste discharges on the quality of waters and sediments of the bay and on the ecological system.

Due to unavoidable program delays and an extended construction period for the combined sewer overflow treatment facility, called the Spring Creek Auxiliary Water Pollution Control Facility, which lasted beyond the program performance period, it was not feasible to perform a post-construction evaluation of the effects of this facility on the water quality of Jamaica Bay. Performance characteristics and operational data on the first two years of the facility's operation are included, however.

PROJECT SCOPE AND CONDUCT

For technical reasons, tasks were developed in three basic categories: pollutional inputs, receiving water and sediment quality, and water quality response to pollutional inputs. Thus, the technical program followed closely the specific objectives established for the study.

Evaluation of pollutional sources contributing to Jamaica Bay included monitoring and characterization of the following inputs.

1. Combined Sewer Overflows. Special monitoring and sampling stations were established at Hendrix Creek, Spring Creek (on two sites) and Thurston Basin. Approximately 30% of the combined sewer overflows entering Jamaica Bay originate in the drainage areas tributary to these sites.

2. Sanitary Sewage (Dry-Weather Flow). Sampling stations were located at the Coney Island, 26th Ward, Jamaica and Rockaway sewage treatment facility effluents.

3. Urban Surface Runoff (Storm Drainage). Two monitoring stations were established: one for evaluation of drainage from a 1,200-acre (ac) area in the southeast area of Queens and the other for a smaller area in the vicinity of Gerritsen Creek in Brooklyn.

4. Industrial Wastes. A detailed analysis of the sources and extent of pollution arising from John F. Kennedy International Airport was made. Other significant industrial sources were also considered.

5. Tidal Exchange. Monitoring programs were established to provide data for estimating the magnitude of the net tidal exchange.

6. Other Sources. Evaluations of landfill practice, dredging, deposition of aerosols and other miscellaneous sources of pollutants were also included in the program.

The basic program of characterization of the water quality of Jamaica Bay involved monitoring cruises with sampling at 15 principal sampling sites at 2-mo intervals. Water samples were taken at high water slack and low water slack to provide both mean water quality conditions and variations of these conditions; and their physical, chemical and biological properties were established. Samples of the sediment were also taken, and quantitative descriptions of benthic animals and sediment characteristics were obtained. Special programs included the determination of primary photosynthetic productivity, bacteriological (coliform) mortality, oxygen transfer, benthic respiration and toxicity factors.

The third section of the technical work program consisted of mathematical modeling of the significant phenomena involved in the response of the bay to the various pollutional influences. These included the oxygen budget, toxic effects, coliform die-away and general dispersion and fate of pollutants within the bay system.

SECTION IV

CHARACTERISTICS OF JAMAICA BAY AND ENVIRONS

The study of the effects of treated wastewater discharges and combined sewer overflows on the water quality of Jamaica Bay has required a proper assessment of the nature of these overflows and the nature of the receiving water responses. Studies of the topography, hydrography and hydrology of the land draining to the bay were necessary to determine the patterns, frequencies and amounts of hydraulic inputs into the bay. Population changes were also considered to determine future waste inputs from sewage treatment facilities. Land use in the drainage area was considered because it affects the hydraulic characteristics of runoff patterns.

TOPOGRAPHY

Geological Characteristics

Long Island originated as the outwash of glaciers which covered the area for the last time in the Pleistocene many thousands of years ago. The most prominent landforms of Long Island are the terminal moraines that form the high ridges in the central and eastern end of the island; the gently sloping outwash plain extending southward from the moraines; the deeply eroded headlands along the north shore; and the barrier beaches along the south shore.

Underlying the surface of Long Island are layers of pervious and impervious sedimentary rock, which provide the island with tremendous groundwater reservoirs. It is estimated, for example, that 60×10^{12} gallons (gal.) of water are stored in these groundwater aquifers. The material underlying Jamaica Bay is entirely glacial deposit and is therefore pervious to inflow and outflow. It is not known whether active exchange of fresh or salt water has occurred through this layer; however, historical records indicate that these layers are not a source of significant fresh water inflow to Jamaica Bay. For example, the New York Harbor Survey, which has recorded salinity in Jamaica Bay since 1926, has recorded no significant changes in the salinity regime in the bay to date. In the 1930's, when groundwater supplies in Brooklyn and Queens were used extensively for water supplies, the water table was drawn down to the extent that salt water penetrated the supply aquifers, indicating an active inflow of salt water through this pervious layer into underlying water-bearing strata. However, by the end of the 1940's substantial recovery had occurred, and by 1965 the water table in all but the northern part of Brooklyn had recovered to a position above sea level. A depression in the water table was caused by continued groundwater pumping in southwest Queens, and salt water is now moving into that area [1].

Surface Features

As has been indicated, the higher regions are areas of glacial deposits. These deposits rise to heights of 211 ft in Queens and 220 ft in Brooklyn. The drainage area to Jamaica Bay is south of this prominent ridge. Most of the land directly adjacent to Jamaica Bay and within approximately 1 mi of its periphery is almost flat. Historically this area was marsh, which has since been filled in for real estate development. For example, on the west side of Jamaica Bay is Barren Island, the location of Floyd Bennett Field; historically the island was separated from the main portion of Long Island and was considerably smaller than its present size. Fill material placed on the north and northwest portions of the island has permanently connected it with Long Island. On the north border of the bay are seven inlets which also are the remains of extensive marsh areas in that region. Landfill operations have narrowed these channels until they are now simply extensions of the combined sewer overflow systems and essentially form a buffering system between the combined sewer outlets and the bay. Located on the eastern border of Jamaica Bay is John F. Kennedy International Airport. Fill for this area was taken entirely from Jamaica Bay, and the present Grassy Bay, which is adjacent to the airport and has a mean depth of approximately 40 ft, was the source of this fill. The only extensive peripheral marshland which still exists is in Nassau County, on the extreme eastern edge of Jamaica Bay. However, even this marsh is rapidly being transformed into filled land for real estate developments. The entire southern border of Jamaica Bay is comprised of Rockaway Peninsula, formed principally by the deposition of sands carried in by ocean currents.

Extensive marsh areas still exist within Jamaica Bay itself. The main island is Rulers Bar Hassock, which contains the City of Broad Channel and the Jamaica Bay Wildlife Refuge. Approximately 3,000 people reside in Broad Channel, and it is through this city that vehicular and subway transportation reaches Rockaway Peninsula from Brooklyn or Queens. Fresh water ponds are present on both sides of Broad Channel and are used by considerable numbers of migrating ducks and other waterfowl, representing about 200 species, throughout the year. In all, the marsh areas cover approximately 4,000 ac, of which only a small portion is accessible by land and the balance by boat. According to previous investigations [2,3], those islands not accessible by land contain large populations of rodents and are unsuitable for bird nesting.

A variety of plant life exists on these marshy areas and consists principally of smooth cord grass intermixed with salt hay and glasswort. However, in the Wildlife Refuge other species have been planted, including autumn olive, chokeberry, black pine and rugosa rose, with the result that a considerable diversity of plant life now exists there [4].

HYDROGRAPHY AND HYDROLOGY

Hydrographic and Hydraulic Characteristics

The present volume of the bay inside the Marine Parkway Bridge at mean tide level is approximately 7 x 10^9 ft^3. The surface area varies from 3.6 x 10^8 ft^2 at mean low water to 5.2 x 10^8 ft^2 at mean high water, which demonstrates the extent of the intertidal marsh areas still remaining in Jamaica Bay. The average depth varies from 13.5 ft at mean low water to 18.5 ft at mean high water, and at mean tide level the average depth is 16.0 ft.

Dredging has considerably altered the natural features of the bay, as have the landfill activities in the peripheral marsh zones. Estimates of the total quantity of material dredged from the bay and its tributary creeks and basins indicate that approximately 70% of the existing volume of the bay can be attributed to dredging.

In addition to sand mining, dredging in Jamaica Bay has been carried out for purposes of navigational channel construction. Surveys carried out approximately 60 years (yr) ago [5], before extensive commercial development of the bay had begun, show that originally the bay was almost exclusively marshland, with shallow channels separating the patches of marsh. In relatively few areas were mean water depths greater than 5 ft.

An engineering study completed in 1909 [5] presented recommendations for the development of deepwater port facilities in Jamaica Bay; although the recommendations were never carried out to any great extent, in the ensuing years Rockaway Inlet was dredged to accommodate medium-draft ships, and the peripheral channels (Island Channel and Beach Channel) were progressively deepened, widened and extended. Continuing activities, including channel maintenance by the U.S. Army Corps of Engineers, have resulted in the present conditions: Rockaway Inlet now has a depth of about 40 ft, whereas the peripheral shipping channels, with nominal depths of 25 ft and widths of about 1,000 ft, extend to Spring Creek on the North Shore and (with somewhat narrower widths) to Head of Bay on the southeast and Bergen Basin on the north of John F. Kennedy International Airport.

The largest single dredging project involved the removal of about 50 x 10^6 cubic yards (yd^3) of material from the Grassy Bay area for fill material used in the construction of Idlewild (now John F. Kennedy) International Airport. Material was removed to a depth of about 40 ft, creating a rather extensive "pot hole" at the head of the bay. Under these conditions, the greater momentum of the waters moving eastward in Beach Channel with flooding tides caused a net counter-clockwise transport of water in the Jamaica Bay system. That is, greater quantities of water moved in than out through Beach Channel. The excess moved northerly through Grassy Bay and out through Island Channel.

However, when at John F. Kennedy International Airport a runway was extended across the southern portion of Grassy Bay to Jo Co Marsh, the circulation patterns were interrupted. It now appears that little, if any, net circulation occurs in Jamaica Bay. Nearly all the water entering the bay on flooding tides is carried via the peripheral channels which essentially terminate in Grassy Bay. On ebbing tides an equivalent quantity of water moves back through the channels and into Rockaway Inlet. A minor exception occurs in Pumpkin Patch Channel, which stretches across the western portion of the bay from Nova Scotia Bar near Rockaway Inlet to the Spring Creek area on the north shore. Because of the shallowness (5 to 10 ft) of this channel, tidal waves are propagated at a slower rate than in Island Channel, resulting in a net flow of water from northeast to southwest in the channel.

Net advective flows in Jamaica Bay are nearly insignificant compared to tidal flows. It is estimated that net daily flow out of the bay (from peripheral inputs) is equivalent to less than 1% of the volume of the bay, whereas the diurnal tidal prism is approximately 60 times greater than this value.

Tides

The tidal wave characteristics of Jamaica Bay are predominantly semidiurnal with a period of 12.42 hours (hr). Thus high tides and low tides occur almost twice each day. The mean tidal range in Jamaica Bay is approximately 5 ft, although this value increases toward the head of the bay. The increase is due to the presence of a standing wave, which is caused by reflection of the tidal wave and is common for closed-end estuaries.

When the sun and moon are either in opposition or in conjunction, tidal ranges occur which are greater than average. These spring tides add approximately 20% to the range in the New York Bight, and similar conditions prevail in Jamaica Bay. Table 1 presents mean and spring tidal ranges for various points in Jamaica Bay.

The rise and fall of the tide at the bay inlet and the associated exchange of water masses through the entrance result in the temporary storage of a large amount of sea water in the bay during high tide and the drainage of this water seaward during low tide. The total volume of water exchanged by this process is known as the tidal prism. The mean tidal prism (volume of water lying between mean high and mean low waters) of Jamaica Bay is 2.51×10^9 ft^3, which is equivalent to 35.9% of the total bay volume at mean tide level. A substantial increase (about 20%) in the tidal prism occurs during spring tides.

Mixing and Stratification

The extensive tide-induced movements of water in Jamaica Bay create sufficient turbulence to effect nearly completely mixed conditions in the

Table 1. MEAN AND SPRING TIDAL RANGES IN JAMAICA BAY

Location	Tidal range, ft Mean	Tidal range, ft Spring
Plumb Beach Channel	4.9	5.9
Barren Island, Rockaway Inlet	5.0	6.0
Beach Channel (bridge)	5.1	6.2
Mill Basin	5.2	6.3
Canarsie Pier	5.2	6.3
Grassy Bay	5.2	6.3
John F. Kennedy Airport	5.3	6.4
Motts Basin	5.4	6.5
North Point, Head of Bay	5.4	6.5

vertical direction in most areas of the bay. Stratification is minimal, even at the bay entrance near the Marine Parkway Bridge. In most areas of low tidal velocity, shallow depths offset stabilizing factors associated with quiescence. Grassy Bay is a noteworthy exception. With little advective transport through this area and a comparatively small relative tidal prism (about 10%), this zone of Jamaica Bay is frequently stratified. However, the fetch in Grassy Bay is at least 3,500 ft, and wind-induced turbulence helps to break up the stratification.

Surface Inflows

There are 18,909 ac within the Jamaica Bay drainage basin which are serviced by combined sewer systems. With approximately 40 inches (in.) of annual rainfall, almost evenly distributed throughout the year, and an estimated runoff factor of 65%, the average discharge from combined sewer systems amounts to approximately 34 mgd. During normal precipitation periods, rain falls on the average every third day. Consequently, there are short periods during which the volumetric discharges from combined sewer overflows are substantially greater than 34 mgd. The peak discharge from combined sewer overflows during a 5-yr storm, which statistically has a 60-minute (min) average intensity of 1.8 in./hr, would amount to 13,500 mgd. The 18,083 ac in the Jamaica Bay drainage basin with separate storm sewers contribute approximately the same quantity of wastewater as do combined sewers. Table 2 shows the breakdown of sewerage system types (including unsewered areas) in the New York City portion of the Jamaica Bay drainage basin.

Water pollution control facility effluents constitute the major sources of nontidal inflow to Jamaica Bay. In dry weather these sources discharge approximately 220 mgd to the bay. The four sewage treatment facilities in the study area operated by the Bureau of Water Pollution

Table 2. CHARACTERISTICS OF JAMAICA BAY DRAINAGE BASIN[a]

Type of discharge	Point of discharge	Drainage area, ac
Combined sewers	Bergen Basin	2,699
	Thurston Basin	2,190
	Spring Creek East	1,382
	Spring Creek West	1,874
	Hendrix Creek	492
	Fresh Creek	2,001
	Paerdegat Basin	5,730
	Sheepshead Bay	291
	Rockaway Peninsula	1,250
Subtotal		18,909
Separate storm sewers	Queens (primarily at Thurston Basin and Bergen Basin)	13,233
	Brooklyn (primarily at Sheepshead Bay)	4,850
Subtotal		18,083
Unsewered	Queens	1,369
	Brooklyn	676
Subtotal		2,045
Total area		39,037

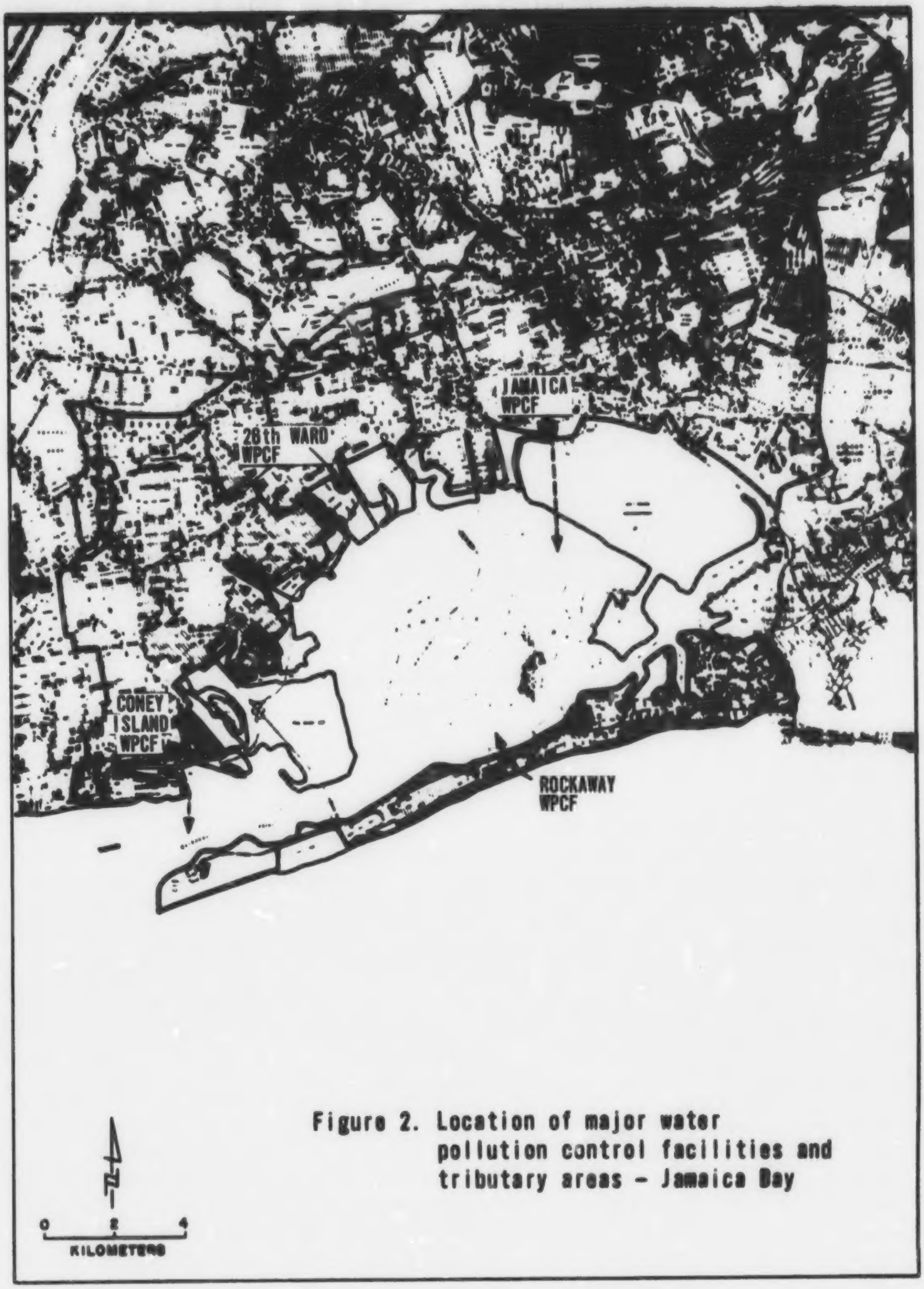
[a] New York City only.

Control of the City of New York are responsible for nearly all the flow from these sources. The locations of these sewage treatment facilities, their points of discharge and their tributary areas are shown in Figure 2. Table 3 presents flow data for the four facilities. The continuous fresh-water inflow contributed from natural streams is insignificant when compared with this dry-weather wastewater inflow. The 13-yr average daily flow from Valley Stream, which empties near the head of the bay, is 2.65 mgd. Motts Creek, 1 mi southwest of Valley Stream in Nassau County, in most cases discharges less than 0.65 mgd into Jamaica Bay.

CLIMATOLOGY

Temperature

In general, New York City's mean annual temperature is slightly higher than that of most places in the United States at the same latitude. Despite its nearness to the ocean, the area has a climate which more closely resembles continental than maritime. The modified continental climate is due primarily to the fact that weather conditions affecting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KILOMETERS

Figure 2. Location of major water pollution control facilities and tributary areas - Jamaica Bay

Table 3. FLOWS TO JAMAICA BAY FROM SEWAGE TREATMENT FACILITIES, 1972

Facility	Flow, mgd
New York City	
Coney Island	99
26th Ward	66
Jamaica	93
Rockaway	19
Military installations	
Floyd Bennett Field	0.3
Fort Tilden	0.3
Nassau County	
Inwood	1.3
Cedarhurst	1.0

the city usually approach from a westerly direction and not from the ocean on the east. The principal exception is during the summer, when sea breezes from the cool ocean surface often moderate the afternoon heat.

The average annual temperature at John F. Kennedy International Airport, the reporting weather station nearest to Jamaica Bay, is 53.2°F (11.8° C). The average monthly temperature at John F. Kennedy International Airport, as shown in Table 4, ranges from 31.5°F (-0.28°C) in February to 75.7°F (24.3°C) in July.

Table 4. AVERAGE MONTHLY AIR TEMPERATURE AND PRECIPITATION AT JOHN F. KENNEDY INTERNATIONAL AIRPORT

		Precipitation, in.	
Month	Temperature, °F	Rainfall	Snowfall
Jan	31.7	3.60	7.7
Feb	31.5	3.44	8.6
Mar	38.3	3.56	5.4
Apr	49.0	3.47	1.0
May	59.9	3.49	0
Jun	70.0	4.11	0
Jul	75.7	4.12	0
Aug	74.4	4.10	0
Sep	67.6	4.49	0
Oct	57.4	3.07	0
Nov	46.3	3.07	1.0
Dec	35.2	3.40	6.0

Because of the shallowness of Jamaica Bay, water temperatures closely reflect ambient conditions in the overlying atmosphere. The average annual temperature of the bay waters is approximately 55°F (12°C), and the gradient within the bay is less than 2°F (1°C) under most conditions. During the coldest periods of the year, ice forms in most of the shallow zones of the bay, and water temperatures lie close to 32°F (0°C). Summertime temperatures in the range of 75 to 80°F (23 to 27°C) are common.

Winds

Data compiled from observations of the U.S. Weather Bureau at the Battery (Manhattan) indicate that the prevailing winds are from the northwest, with a significant southerly component. From October through May the winds are predominantly from the northwest and during the summer months are from the south.

The total annual wind movement averages almost 30% from the northwest and approximately 15% from the south. Over 50% of the winds in New York City in excess of 25 miles per hour (mph) are from the northwest, whereas similar winds from the east account for only 0.3% of the total.

Precipitation

In the Jamaica Bay area precipitation is both moderate and evenly distributed throughout the year, as shown in Table 4. Most of the rainfall from June through September comes from thunderstorms and therefore is usually of short duration but relatively intense. From October to April, precipitation is generally associated with widespread storm activity, so that day-long rain or snow is common. The average annual precipitation increases from about 40 in. near Rockaway to about 47 in. in the northern and western suburbs of New York City. The average annual precipitation is 43.93 in. at John F. Kennedy International Airport. The average monthly rainfall is fairly evenly distributed, with August having the most rainfall and February the least.

On the basis of U.S. Weather Bureau snow measurements, the average annual snowfall at John F. Kennedy International Airport is 29.8 in. (approximately equivalent to 4 in. of water), ranging from 1.0 in. in November to 8.6 in. in February. The average monthly snowfalls are presented in Table 4.

Evaporation

Evaporation data in the vicinity of Jamaica Bay appear in the evaporation maps published by the U.S. Weather Bureau. The average Class A pan evaporation is approximately 40 in. (1946-1955 average), whereas the annual lake evaporation is approximately 30 in., of which 73% occurs in the period from May to October. Thus, precipitation and evaporation nearly offset one another in terms of hydraulic input to Jamaica Bay.

DEMOGRAPHY

New York City and Metropolitan Area

Population trends in New York City and the surrounding metropolitan area are expected to parallel those in the rest of the United States; that is, small increases or actual decreases in the central city population with relatively large growth in the surrounding communities. It is projected that the population of New York City will decrease from the present 7.75 million persons to 7.68 million in 1985. However, the total metropolitan area population is projected to increase nearly 40% (from 17.2 million to 23.7 million) in the same period.

Borough Populations

The populations of the boroughs of Manhattan, Brooklyn and Queens and of Nassau County are shown in Figure 3 for the period from 1850 to the year 2000. The latest census, taken in 1970, showed that over 2.6 million people resided in Brooklyn, just under 2.0 million were in Queens and slightly over 1.4 million lived in Nassau County. Projections of populations for these three counties and for Manhattan are given in Figure 3 and indicate that both Brooklyn and Manhattan will show decreases in population up to 1985 and that continued decreases may be expected up to the year 2000. In Queens and Nassau counties a definite leveling is indicated by the projection of the Regional Plan Association [6].

Drainage Area Populations

The Bureau of Water Pollution Control maintains an estimate of the population served by its sewerage system. Estimates of populations served by the Coney Island, 26th Ward, Jamaica and Rockaway water pollution control facilities (WPCF) are given in Table 5. For the most part, these population changes parallel those in the boroughs; however, small changes do occur and were considered in the projection of the drainage area populations.

Drainage area populations were projected using the ratio of the population served by a particular water pollution control facility to that of the entire borough. It was evident from following these trends through time that either the ratio increased as the connected population increased or the ratio decreased as the population served remained static or increased at a growth rate somewhat less than that of the county as a whole. In each case, however, this ratio leveled off such that a constant value could be used to make the projections indicated in Table 5. For the population as a whole, it is anticipated that the percentage increase in connected population between 1960 and 1970 will be only 3.7% and the increase from 1970 to 1980 only 0.2%. However, for the sewage treatment facilities in Brooklyn a net decrease in population served is expected to occur between 1970 and 1980. Only a small in-

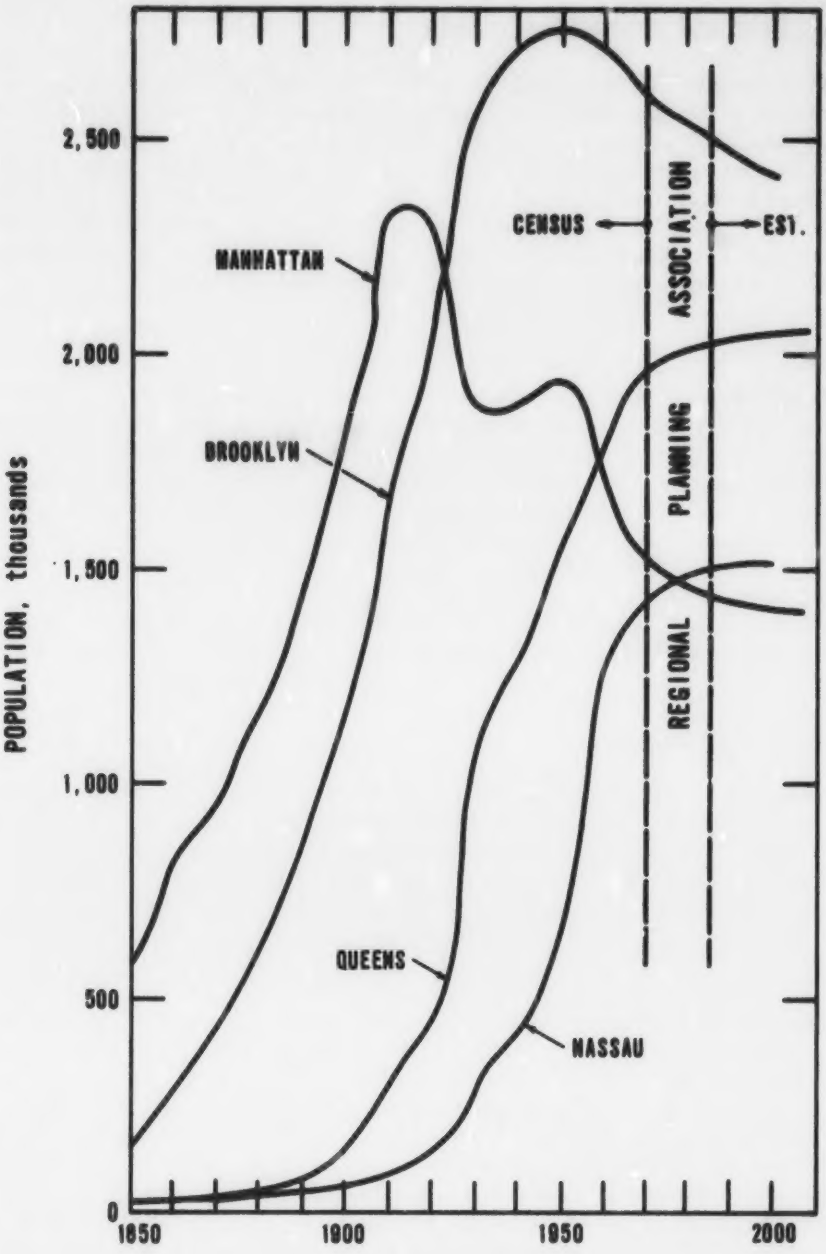

Figure 3. Historical and projected population surrounding Jamaica Bay

Table 5. POPULATIONS SERVED BY SEWERAGE SYSTEMS IN THE BOROUGHS OF BROOKLYN AND QUEENS, 1910-2000 (thousands)

Year	Brooklyn			Queens			Total connected population	Increase over previous period	Percent increase	Source of data	
	Borough total	Coney Island WPCF	26th Ward WPCF	Borough total	Jamaica WPCF	Rock-away WPCF				County	Plant
1910	1634.4			284.0						USCB[a]	BWPC[c]
1920	2018.4	133.4	321.6	469.0	112.8	21.5	589.3		105.7	USCB	BWPC
1930	2560.4	434.2	398.0	1079.1	345.4	34.9	1212.5	623.2	13.8	USCB	BWPC
1940	2698.3	536.0	391.4	1297.6	412.4	41.2	1381.0	168.5	7.1	USCB	BWPC
1950	2738.2	588.3	364.0	1550.8	473.1	54.0	1479.4	98.4	6.8	USCB	BWPC
1960	2627.3	612.7	360.3	1809.6	538.3	69.6	1580.9	101.5	3.7	USCB	BWPC
1970	2550.0	617.1	374.8	1900.0	566.2	81.4	1639.5	58.6	0.2	RPA[b]	
1980	2475.0	608.8	371.2	1925.0	573.6	90.1	1643.7	4.2	0.1	RPA	
1990	2450.0	602.7	367.5	1950.0	581.1	95.6	1646.9	3.2	-1.1		
2000	2390.0	587.9	358.5	1960.0	584.1	98.0	1628.5	-18.4			

[a] United States Census Bureau.
[b] Regional Plan Association.
[c] Bureau of Water Pollution Control.

crease is anticipated for the Jamaica facility in Queens, whereas a 10% increase is expected for the Rockaway treatment facility.

Because population changes are projected to be relatively small for the next 30 yr, it is expected that waste flows to Jamaica Bay from the water pollution control facilities will remain near the present levels of discharge.

LAND USE

Present Land Use

Present land uses for New York City and the boroughs of Manhattan, Brooklyn and Queens as compiled by the Department of City Planning are given in Table 6. As indicated in the table, the major uses of land are for residence, streets, and parks and outdoor recreation.

The relative balance of land use in the drainage area of Jamaica Bay is consistent with that indicated in Table 6. In Brooklyn, the entire drainage area is composed for the most part of residential areas. Commercial and industrial use is relatively small, and industrial use is limited to light industry. The drainage area in Queens is similar, but some heavy industry is present. The major concentration of light industry is located near the John F. Kennedy International Airport. More detailed descriptions of the drainage areas of the combined sewers monitored will be given in Section VII with the descriptions of those areas.

Projected Land Use

No major changes in land use are anticipated for any of the areas draining to Jamaica Bay. Development of housing on existing landfill areas just north of the Southern Belt Parkway will increase populations in those areas, and development of housing in Nassau County in the present marsh area should increase populations there; however, drainage from those areas is to two water pollution control plants in Nassau County. Plans for the Jamaica area of Queens as proposed by the Regional Plan Association [7] will, if implemented, result in an intensified commercialization of that area. Such a development would, of course, intensify the daily variations in sewer flow from that area to produce a flow similar to that which occurs at the present time in Manhattan; however, the net increase in flow from that area is anticipated to be small.

Table 6. LAND USE IN NEW YORK CITY, BROOKLYN AND QUEENS, 1959-1969

	New York City		Brooklyn		Queens	
Use	ac	%	ac	%	ac	%
Open uses & vacant land						
Licensed parking lots	385.6	0.2	94.1	0.2	116.6	0.2
Other[a]	25,656.3	12.5	3,292.3	6.6	5,924.5	8.0
Total	25,041.9	12.7	3,386.4	6.8	6,040.7	8.2
Parks & outdoor recreation	35,468.7	17.3	10,356.9	20.6	11,448.3	15.6
Residence						
1-family detached	19,066.9	9.3	2,151.1	4.3	11,304.2	15.4
1-family attached	4,576.9	2.2	1,820.7	3.6	2,068.8	2.8
2-family	9,875.3	4.8	4,404.1	8.8	3,805.8	5.2
Walk-up multiple[b]	9,139.5	4.5	3,549.8	7.1	2,367.8	3.2
Elevator multiple[b]	4,865.8	2.4	1,224.9	2.4	1,200.2	1.6
Total	47,524.4	23.2	13,150.7	26.2	20,746.8	28.3
Commercial & industrial						
Commercial & retail[c]	2,176.9	1.1	503.2	1.0	744.2	1.0
Office	345.9	0.2	37.1	0.1	38.4	0.1
Light industry	2,354.1	1.2	603.4	1.2	663.7	0.9
Warehouse & storage yards	1,174.2	0.6	424.2	0.8	396.6	0.5
Automotive	1,575.8	0.7	489.9	1.0	484.4	0.7
Heavy industry	4,431.6	2.1	1,412.2	2.8	1,253.2	1.7
Total	12,058.5	5.9	3,470.0	6.9	3,580.5	4.9
Public & private institutions	12,399.1	6.1	2,083.2	4.1	4,102.2	5.6
Transportation	9,641.0	4.7	1,800.9	3.6	6,201.9	8.4
Total net area	143,133.6	69.9	34,248.1	68.2	52,120.4	71.0
Mapped Streets	61,547.4	30.1	15,995.9	31.8	21,285.6	29.0
Total gross area	204,681.0	100.0	50,244.0	100.0	73,406.0	100.0

[a] Includes farms, used automobile lots, licensed junk yards and accessory parking lots.

[b] Includes hotels and motels.

[c] Does not include store space in ground floors of buildings having other predominant land use.

Source: Department of City Planning from Sanborn Map Company data.

SECTION V

JAMAICA BAY ECOSYSTEM

QUALITY OBJECTIVES AND CRITERIA

Uses of Jamaica Bay

Jamaica Bay supports a wide spectrum of beneficial uses. As a consequence the quality requirements of the waters and environment of the bay are necessarily complex, and, as might be anticipated, conflicts among beneficial uses occur in a number of cases. Competition for space or facilities is an expected major factor, but a certain degree of competition also arises from detrimental factors associated with use. Table 7 lists the known uses of Jamaica Bay and its environs and presents in general terms the detrimental factors and environmental quality requirements for each use.

Table 7. USES OF JAMAICA BAY AND ENVIRONS--DETRIMENTAL FACTORS AND ENVIRONMENTAL REQUIREMENTS

Use	Potential detrimental factors	Environmental quality requirements
Shipping	Floating debris Navigational hazards	
Dredging	Unnatural bottom profile Increased turbidity Upsets benthic community Destroys marsh community	
Landfill	Destroys marsh and/or benthic communities Aesthetically objectionable Leachates affect water quality	
Air terminals	Oil spills--runoff Unburned fuels from aircraft Noise	
Residence	Exclusive use of area	Relative freedom from odors and noise
Wastewater disposal	Suspended materials cover benthic communities Organic materials cause oxygen depletion	

Table 7 (Continued). USES OF JAMAICA BAY AND ENVIRONS--DETRIMENTAL FACTORS AND ENVIRONMENTAL REQUIREMENTS

Use	Potential detrimental factors	Environmental quality requirements
	Nutrients stimulate algal blooms Oils, greases and floatables Potential pathogenic agents Toxicity to aquatic life Aesthetic factors (color, odor, turbidity)	
Boating	Navigational hazards	Aesthetic acceptability (color, odor, turbidity, floatables, oils)
Fishing		Aesthetic acceptability Abundance of fish Relates to food chain, toxicity, temperature, dissolved oxygen
Wildlife propagation, birds, waterfowl	Exclusive use of area	Undisturbed habitat Adequate food
Fish		Adequate food Dissolved oxygen
Shellfish		Low levels of pathogenic microorganisms Suitable substrate Adequate food
Swimming	Navigational hazard	Aesthetic acceptability, low levels of potential pathogenic agents
Aesthetic enjoyment		Aesthetic acceptability

It is worthy of comment relative to Table 7 that most uses of the bay environment result in a preponderance of detrimental factors over and against environmental quality requirements. Except for residence, it would be difficult to assign any controllable quality requirements to these uses. It should also be noted that beneficial uses are extremely sensitive to quality conditions.

Water Quality Requirements

Aesthetics--

Aesthetically pleasing waters add to the quality of human experience and as such have a value which although difficult to quantify cannot be ignored. In addition to being pleasant to observe, attractive waters enhance the values of adjoining properties and may provide a focal point of pride in the community.

The appearance of pollution or the thought of its existence, even in an abstract sense, reduces aesthetic value. The knowledge that water is clean enhances both direct and indirect aesthetic appreciation. Furthermore, attitudes stimulated by appreciation of a resource may produce tangible benefits through public desire for the maintenance of attractive conditions.

It is clear that Americans are becoming increasingly concerned about the aesthetic quality of the environment. Expectations will likely rise with increases in education and leisure time and will undoubtedly be reflected in continuing and intensified public demand for clean water. Therefore, the recognition, identification and protection of the aesthetic values and qualities of water should be a primary objective in all water quality management programs. These needs are, ironically, most urgent in areas where pollution problems are most acute, namely, in cities and large metropolitan areas where population and pollutional discharges are most heavily concentrated.

Wildlife is a significant element of the aesthetics of the environment. Beyond the direct experience of viewing is the satisfaction of knowing that these life forms are present. Conversely, periodic disruptions of the aquatic environment by pollution (as reflected in fish kills, damaged waterfowl, odors and noxious vegetative growth) degrade aesthetic qualities and appreciation. The losses extend beyond the periods in which the undesirable conditions occur. An estuary that periodically is offensive will lose much of its aesthetic value.

Furthermore, when aesthetically unappealing conditions exist, it is almost certain that problems associated with other beneficial uses also exist. One example is odors due to release of reduced (sulphurous) gases, which can occur only when dissolved oxygen conditions are inadequate to support a healthy biota. Oils and greases on the water surface inhibit oxygen transfer as well as producing an undesirable visual impression and creating undesirable accumulations at the shoreline and in the sediments. Therefore, the maintenance of aesthetically acceptable quality conditions in surface waters should be of principal concern in establishing objectives for any water quality management program, with particular attention to biological factors relating to aesthetic acceptability.

Because many of the relationships between biological response and more readily determinable environmental quality factors are only loosely defined at the present time, it is considered essential to involve other parameters in the development of criteria for the protection of aesthetic values. Furthermore, in some cases the biological implications may be marginal, whereas the asethetic impact may be substantial. Such factors as settleable solids, odiferous materials, turbidity elements and floatable materials are some of the candidates for selection.

Health--

Surface waters have recreational potential wherever there are people and are likely to be used for recreation even if grossly polluted. Moreover, demands on water for recreational use are becoming extremely intense, particularly in urban areas such as New York City. Therefore, it can be readily deduced that recreational uses of water resources in close proximity to urban areas should receive thorough consideration in the designation of water quality improvement objectives and in the selection of water quality criteria.

A principal consideration relative to recreational uses is the suitability of the water resource from a health or epidemiological standpoint. Requirements should be based on the need to minimize, insofar as possible, the risk of contracting the disease through use of the water for recreation, or at least to reduce the probability to a level not statistically significant from that for waters considered to be unpolluted.

Unfortunately there does not now exist sufficient epidemiological evidence which offers a universally acceptable quality parameter upon which to base criteria for recreational water use. Secondly, as technology increases, new phenomena relating to the transmission of potential pathogenic agents and their modes of infection are coming to light. In general, new knowledge in this area usually results in more stringent criteria and standards related to accepted parameters.

Therefore, it is recommended that the existing health-oriented requirements, as manifest in standards promulgated by appropriate regulatory agencies, be retained as criteria until further evidence warrants their modification or revision.

Aquatic Biota--

Estuaries are recognized as being of critical importance to the ecosystem and in man's harvest of economically useful living marine resources. It is in these areas that the maximum conversion of solar energy for plant life takes place, and they are justly identified as *nurseries* because so many animals utilize them for feeding in their early life stages. Some species, such as the oyster, spend their entire life span in the estuary, while the shrimp resides there only as a juvenile.

Therefore, protection of the aquatic biota of Jamaica Bay should be of primary concern in the establishment of water quality criteria and standards, and it is recommended that these criteria be oriented toward management of the ecology to provide for the intended uses of the bay.

Tentative Criteria

Tentative water quality criteria for Jamaica Bay are presented in Table 8. For purposes of establishing objectives and criteria, two major categories of beneficial use are suggested: recreation, with the subcategories aesthetics and health, and protection of aquatic biota.

Table 8. TENTATIVE WATER QUALITY CRITERIA FOR JAMAICA BAY

Quality characteristics	Categories of use: Recreation: Aesthetics	Categories of use: Recreation: Health	Categories of use: Protection of aquatic biota	Related water characteristics
Total coliforms		Median ≤ 24/ml		Total coliform
Fecal coliforms		Log mean ≤ 2/ml		Fecal coliform
Dissolved oxygen			>5.0 mg/l	BOD Biostimulants Settleable solids Suspended solids
Microplankton	<500 cells per ml			Biostimulants Turbidity
Benthic animal diversity			>80% of normal	Toxicity Settleable solids
Transparency (Secchi disc)	>2 m			Turbidity elements Biostimulants
Sediment BOD			<4 mg/g	BOD Settleable solids Suspended solids
Chlorinated hydrocarbons			<50 µg/l	Chlorinated hydrocarbons
Floatable hexane extractable materials	<2 mg/m^2 (water) <0.3 g/m^2 (shore)			Oils and greases

Table 8 (continued). TENTATIVE WATER QUALITY CRITERIA FOR JAMAICA BAY

	Categories of use			
Quality characteristics	Recreation		Protection of aquatic biota	Related water characteristics
	Aesthetics	Health		
Floatable particulates			(none yet proposed)	Floatable particulates
Temperature	$T < 85^\circ F$		$\Delta T < 4^\circ F$ (winter) $\Delta T < 1.5^\circ F$ (summer)	Temperature
Color	<5 mg/l^a above normal			Color
pH	$6.5 < pH < 8.5$			Acidity Basicity
Odor	No objectionable odor			Odor Organics

[a] Standard chloroplatinate

QUALITY OF JAMAICA BAY

An evaluation of the water and sediment quality in Jamaica Bay is essential for assessment of the effects of wastewater discharges on the bay, especially to establish a receiving environment quality baseline against which to judge improvement in water and sediment quality due to operation of the Spring Creek combined sewer overflow treatment facility and other subsequent facilities that may be provided for the abatement of pollution from combined sewer overflows. After evaluation of all readily available historical data on the quality of Jamaica Bay, a sampling program was established and conducted for spatial and temporal characterization of water and sediment quality of Jamaica Bay.

Fifteen stations, providing a complete representation of effects of tidal action, wastewater inflow and marshland on water and sediment quality throughout Jamaica Bay, were sampled over a 3-yr period. Locations of the sampling stations are shown on Figure 4. Water samples taken at mid-depth on high and low slack water for each survey were analyzed for temperature, transparency, total suspended solids, volatile suspended solids, pH, chloride, dissolved oxygen (DO), biochemical oxygen demand (BOD), Kjeldahl nitrogen, organic nitrogen, ammonia, nitrate, total phosphate, orthophosphate, hexane extractable material (HEM), total coliform bacteria, fecal coliform bacteria, fecal streptococci bacteria and microplankton. Vertical hauls with a plankton net were made at each sampling station for zooplankton analysis. Sediment samples were analyzed for temperature, BOD, dry solids content, sand fraction, silt fraction, clay fraction, Kjeldahl nitrogen, HEM, total sulfide, total phosphate and benthic organisms.

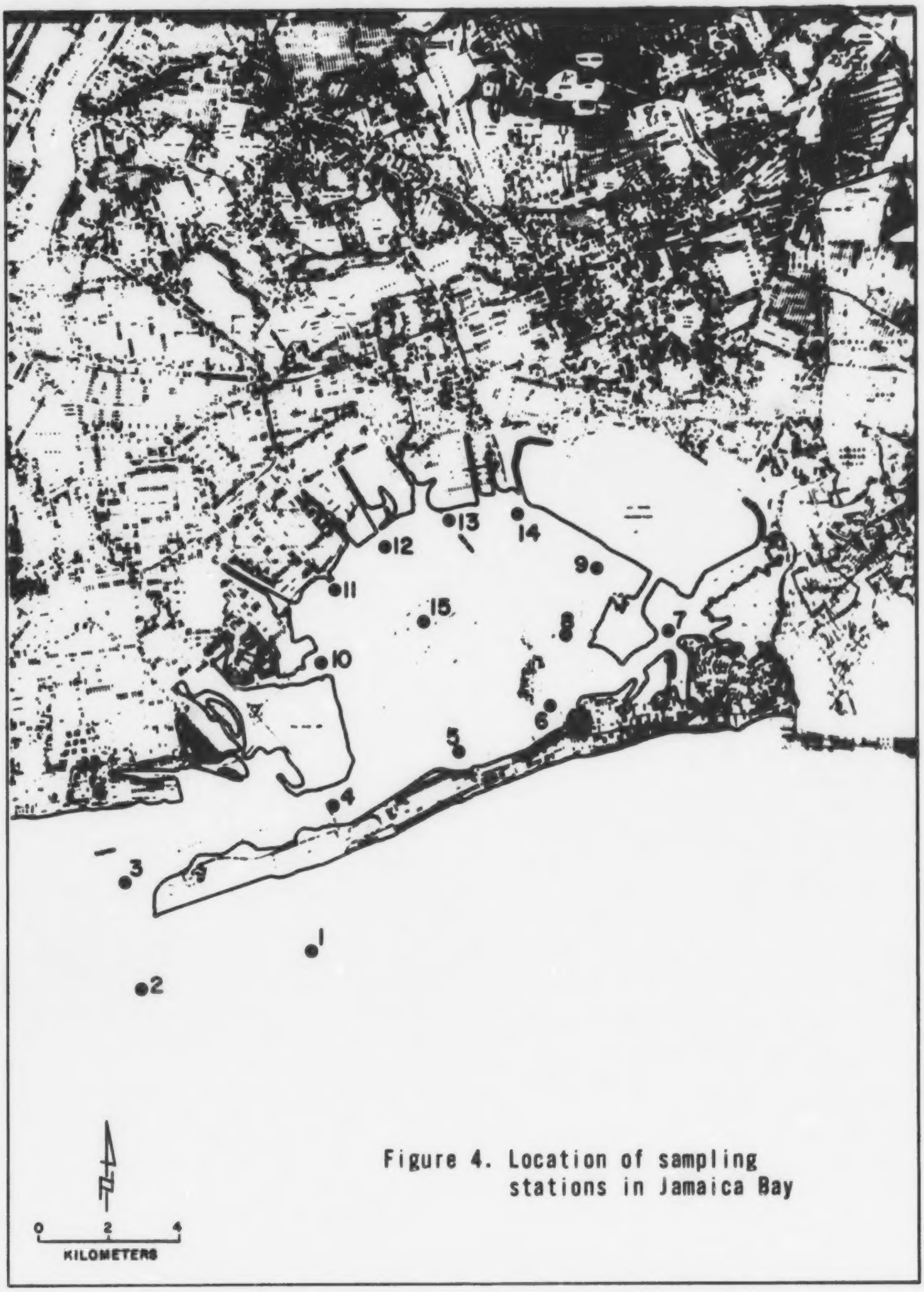
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Figure 4. Location of sampling stations in Jamaica Bay

Receiving Water Quality

To provide a general description of the quality of the waters of Jamaica Bay, results obtained during the 3-yr program of sampling and analysis were aggregated and averaged to reflect summer and winter conditions. (Results obtained during the surveys of 11 June 1969, 21 August 1969, 1 July 1970 and 17 August 1970 were included in the summer average; results obtained during the surveys of 14 December 1968, 19 February 1969, 17 December 1969 and 2 March 1970 were included in the winter average.) Summertime and wintertime average water quality characteristics are represented in Jamaica Bay by isopleths and by value at the mouth of Rockaway Inlet and in the New York Bight.

Detailed individual water quality analyses for the 3-yr sampling program are provided in Appendix D, Volume II, Supplemental Data.

Temperature--

Summertime average water temperatures in Jamaica Bay increase landward from about 21°C at Rockaway Inlet to over 23°C in Head of Bay and in the north channel in the vicinity of the Spring Creek drainage basins, as shown in Figure 5. This temperature gradient is due to ambient air temperatures, which have a more pronounced effect on the shallow bay waters than on the ocean waters, and to the effects of discharges of relatively warm stormwater runoff and combined sewer overflows.

Wintertime average water temperatures in Jamaica Bay, shown in Figure 6, exhibit less spatial variation than do summertime temperatures. The coldest wintertime average temperature, of less than 1.5°C, appears to occur in Head of Bay. There appears to be a slight warming influence on the bay created by the effluents from the 26th Ward Water Pollution Control Facility and the Spring Creek combined sewer overflows.

Transparency--

Average summertime and wintertime transparency isopleths, determined from Secchi disc depth measurements and presented in Figures 7 and 8, respectively, exhibit a generally increasing transparency from back-bay areas to the inlet of the bay. The wintertime average transparencies of the bay are greater than summertime averages, with the largest differences occurring in the north channel and Grassy Bay. In these areas, the summertime average water transparencies increase from about 0.6 m to twice that value, or 1.2 m. Correspondingly, the summertime average water transparency at the entrance to Rockaway Inlet is 1.68 m, whereas the wintertime average is 2.50 m.

Total Suspended Solids--

Summertime average total suspended solids concentrations, shown in Figure 9, are not significantly different from wintertime average total

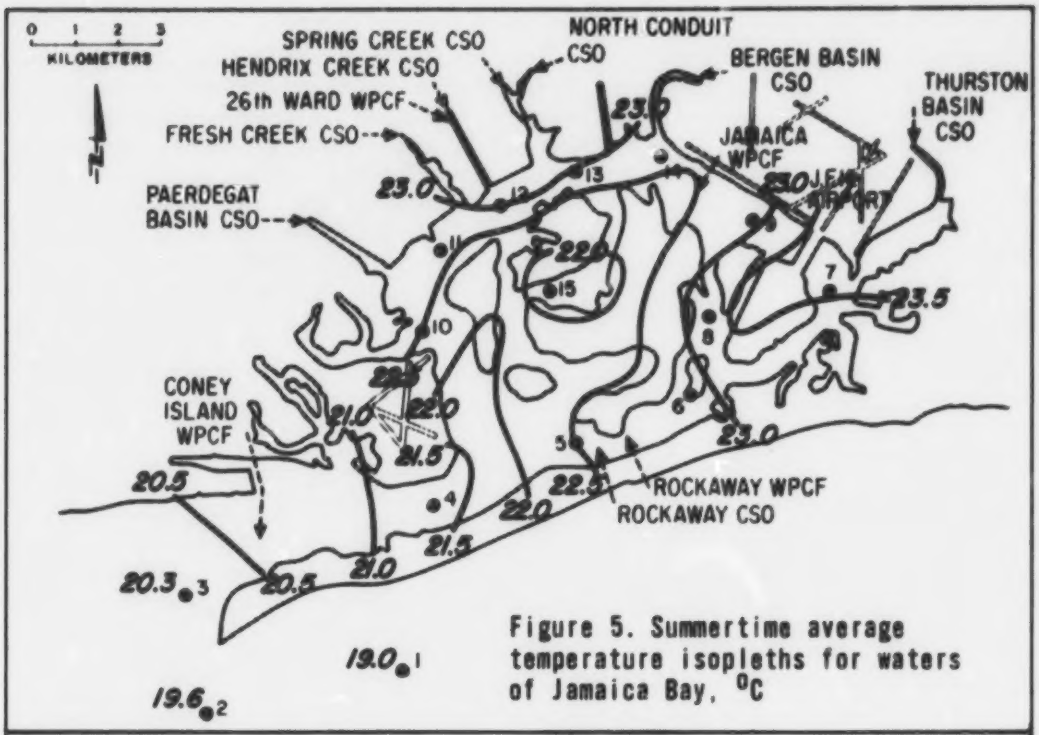
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Figure 5. Summertime average temperature isopleths for waters of Jamaica Bay, °C

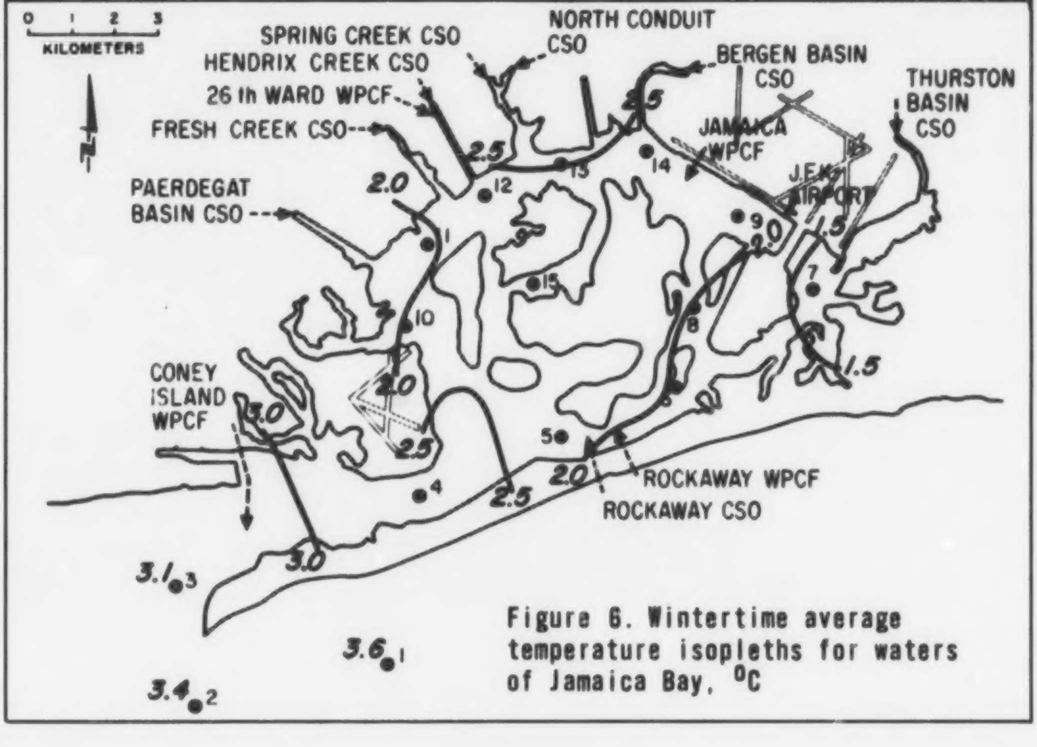
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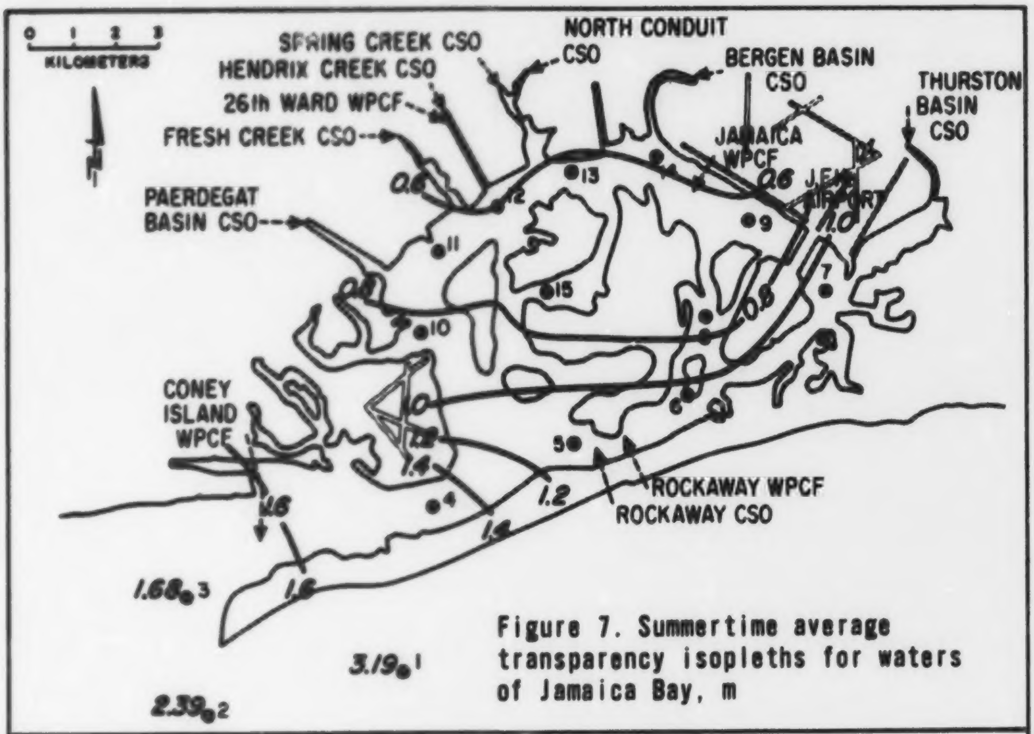
Figure 6. Wintertime average temperature isopleths for waters of Jamaica Bay, °C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3.19 1
2.39 2

Figure 7. Summertime average transparency isopleths for waters of Jamaica Bay, m

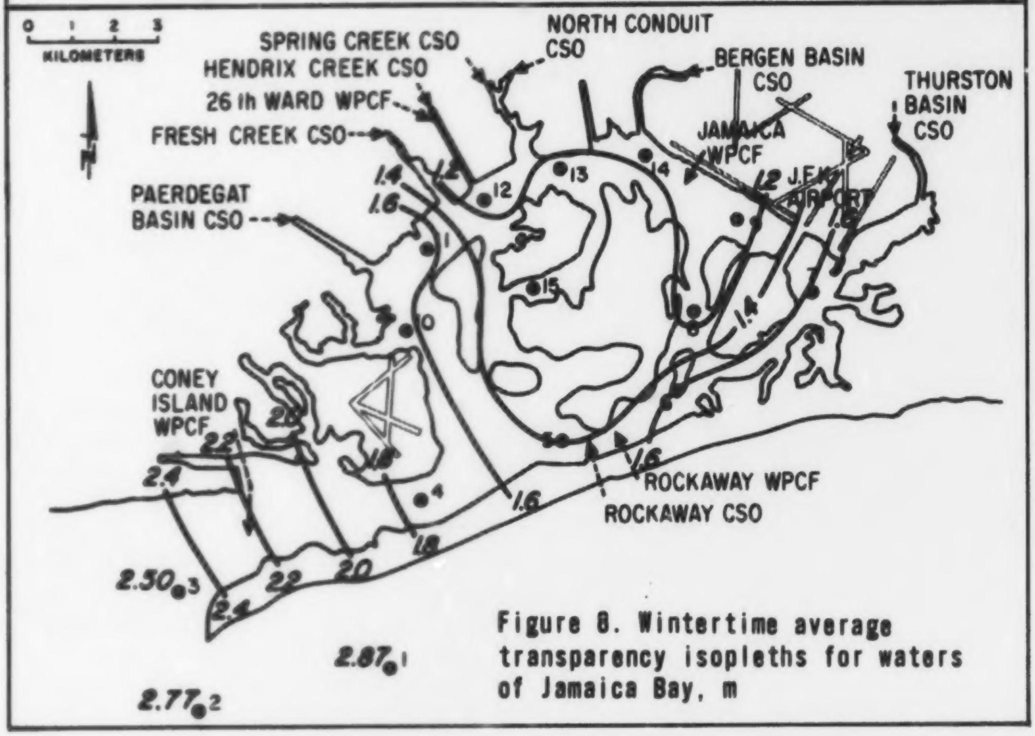
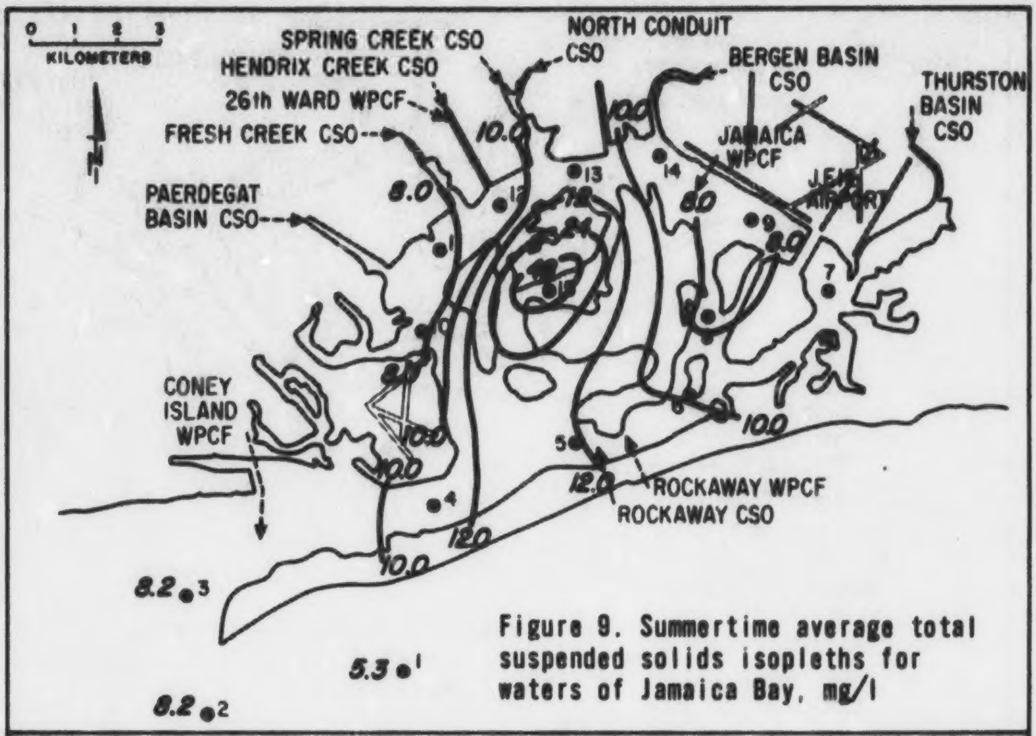

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
1.2
1.4
1.6
1.8
2.0
2.2
2.4
13
14
12
11
15
10
4
2.50 3
2.87 1
2.77 2

Figure 8. Wintertime average transparency isopleths for waters of Jamaica Bay, m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KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
10.0
8.0
12.0
8.2 3
5.3 1
8.2 2

Figure 9. Summertime average total suspended solids isopleths for waters of Jamaica Bay, mg/l

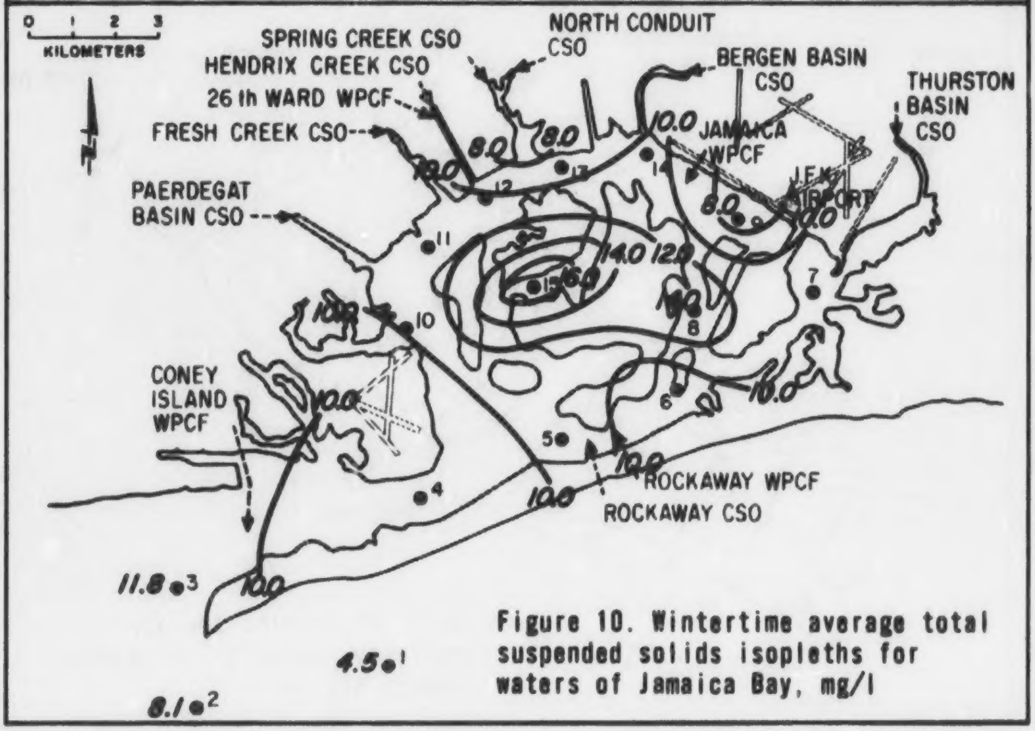

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
10.0
8.0
12.0
14.0
16.0
11.8 3
4.5 1
8.1 2

Figure 10. Wintertime average total suspended solids isopleths for waters of Jamaica Bay, mg/l

suspended solids, shown in Figure 10, except in mid-bay channels, e.g., Pumpkin Patch Channel, where the summertime average total suspended solids concentration was 53 mg/l as compared to a wintertime concentration of 19 mg/l.

Volatile Suspended Solids--

Isopleths of average volatile suspended solids concentrations for summertime and wintertime are shown on Figures 11 and 12, respectively. Summertime concentrations are generally higher, especially in the center of the bay (Pumpkin Patch Channel), where for both seasons the highest spatial concentrations are also observed. Concentrations of volatile suspended solids appear to remain nearly constant both spatially and temporally along the Rockaway Peninsula beaches.

pH--

The distributions of average pH in Jamaica Bay during summertime and wintertime conditions are shown in Figures 13 and 14, respectively. In Grassy Bay the summertime average pH is depressed about 0.3 units from the average pH of 7.8 occurring at the Rockaway Inlet and to a somewhat lesser degree (0.2 units) in the north channel and Head of Bay. The wintertime average pH values are quite uniform throughout the bay and in the New York Bight, with all reported average values being 7.8 or 7.9 units.

The seasonal variation in pH value may be due in part to metabolic activity because during photosynthesis algae (phytoplankton) utilize carbon dioxide from the water, which causes a decrease in acidity and a concomitant increase in pH value. Conversely, respiration by plants and animals increases carbon dioxide levels, which causes a decrease in pH value. In Jamaica Bay, algal photosynthetic activity is highest and respiration is lowest in the winter, which is reflected in the seasonal differences of pH distribution.

Chlorosity--

The spatial distributions of average summertime and wintertime chlorosities in Jamaica Bay are quite similar, as shown in Figures 15 and 16. Because the only significant fresh water flows to the bay are sewage treatment facility effluents and stormwater runoff, and these are small compared to the tidal exchange occurring through Rockaway Inlet, a very small salinity gradient exists in Jamaica Bay. Average summertime and wintertime chlorosities of less than 14 grams per liter (g/l) in Grassy Bay increase almost uniformly to 17 g/l in the New York Bight.

Dissolved Oxygen--

Distinct seasonal and spatial variations in average dissolved oxygen concentrations occur in Jamaica Bay and are shown in Figures 17 and 18,

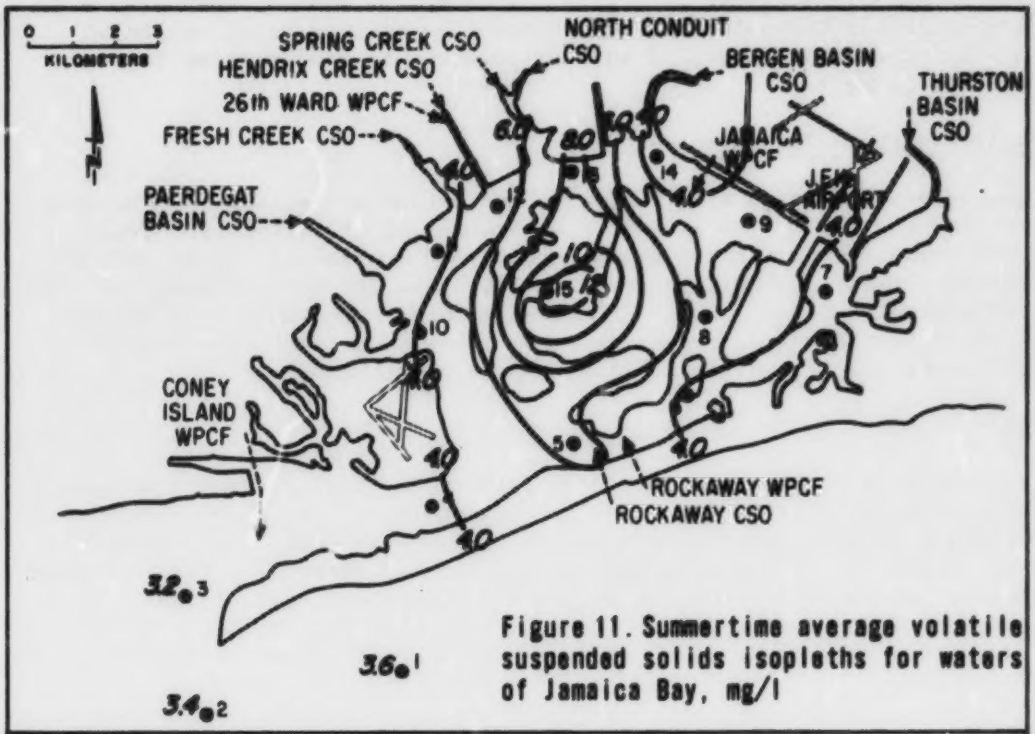

0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
ROCKAWAY WPCF
ROCKAWAY CSO
6.0
8.0
10
4.0
10
12
15
12
14
9
1
7
10
8
5
4.0
3.2 3
3.6 1
3.4 2

Figure 11. Summertime average volatile suspended solids isopleths for waters of Jamaica Bay, mg/l

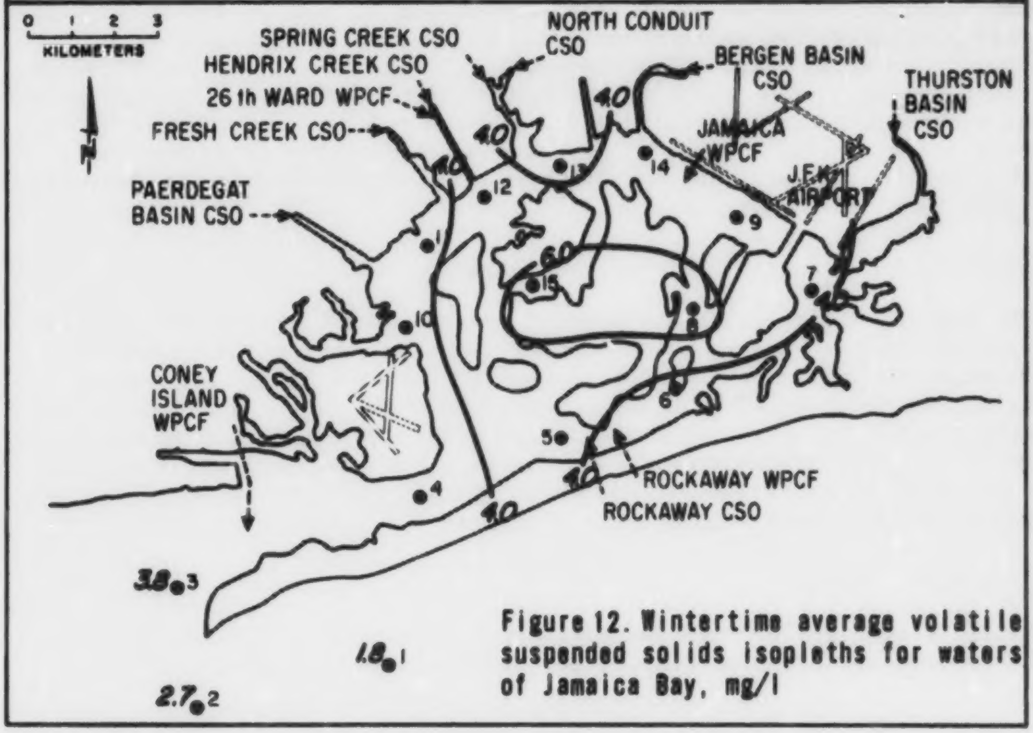

0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
ROCKAWAY WPCF
ROCKAWAY CSO
4.0
6.0
12
13
14
9
1
15
8
7
10
6
5
4
3.8 3
1.8 1
2.7 2

Figure 12. Wintertime average volatile suspended solids isopleths for waters of Jamaica Bay, mg/l

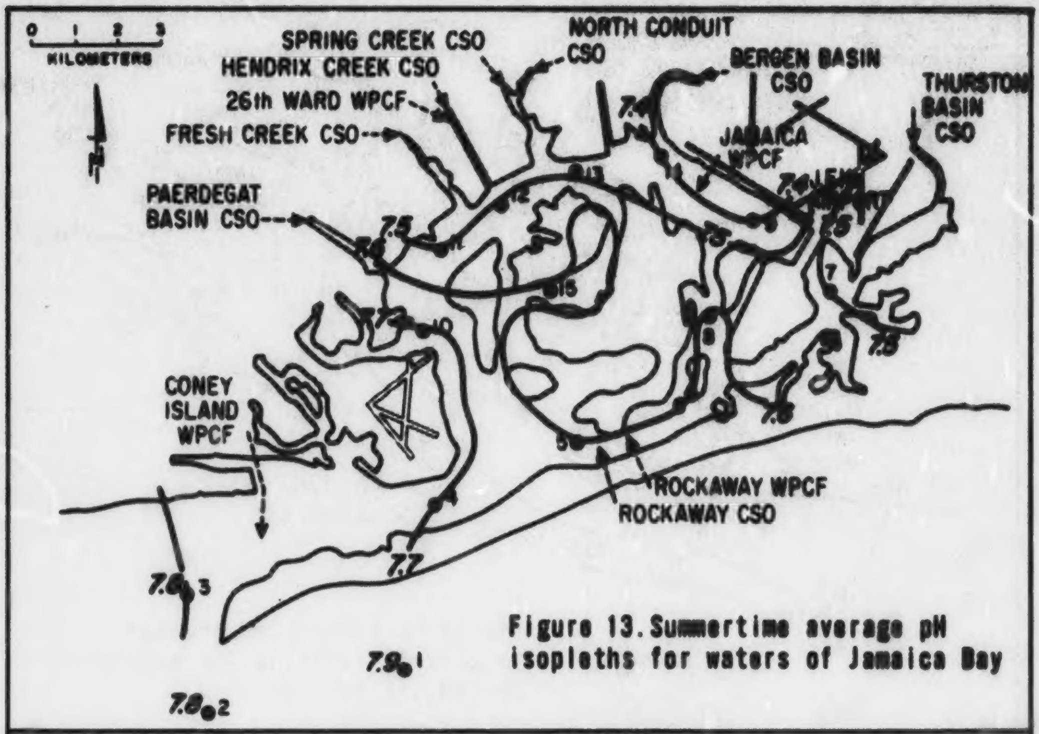
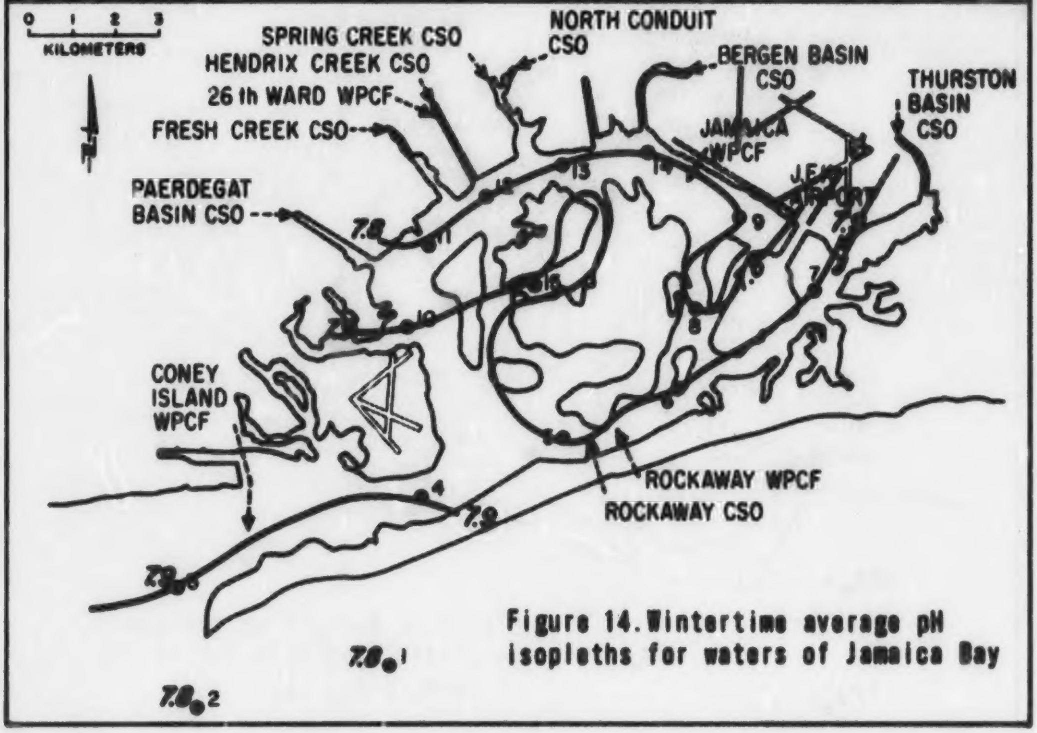

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
BERGEN BASIN CSO
26th WARD WPCF
THURSTON BASIN CSO
FRESH CREEK CSO
JAMAICA WPCF
PAERDEGAT BASIN CSO
J.F.K.
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
7.5
7.7
7.6
7.9
7.8
15
13
12
11
10
9
8
7
5
3
2
1

Figure 13. Summertime average pH isopleths for waters of Jamaica Bay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KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
BERGEN BASIN CSO
26th WARD WPCF
THURSTON BASIN CSO
FRESH CREEK CSO
JAMAICA WPCF
PAERDEGAT BASIN CSO
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
7.8
7.9
7.5
16
14
13
12
11
10
9
8
7
4
2
1

Figure 14. Wintertime average pH isopleths for waters of Jamaica Bay

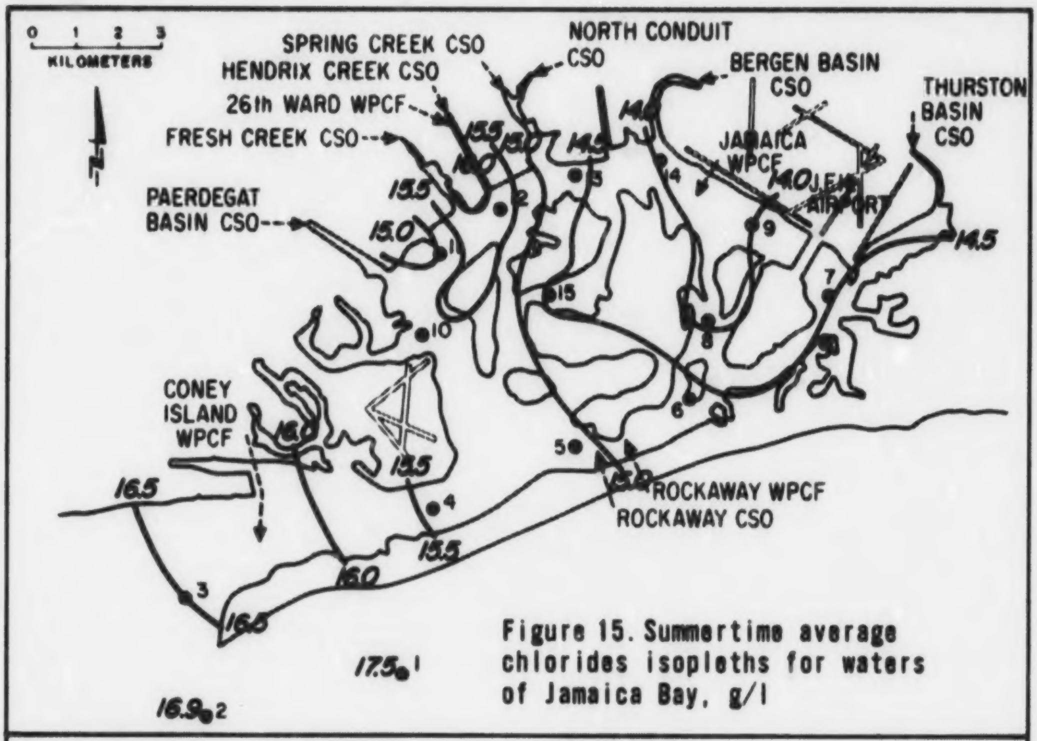

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
15.5
15.0
16.0
15.5
15.0
14.5
14.0
14.0
14.5
16.0
16.5
15.5
15.5
16.0
16.5
15.0
17.5 1
16.9 2
3
4
5
6
7
8
9
10
11
12
13
14
15

Figure 15. Summertime average chlorides isopleths for waters of Jamaica Bay, g/l

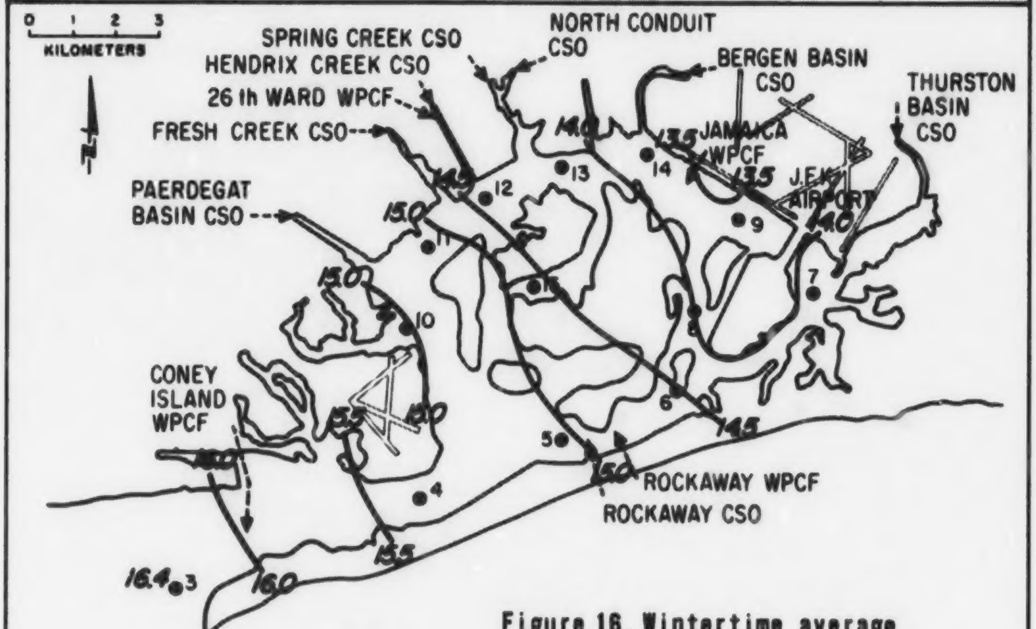

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
14.0
13.5
13.5
14.0
14.5
15.0
15.0
15.5
16.0
16.0
15.5
16.0
15.0
14.5
16.4 3
17.9 1
17.2 2
4
5
6
7
9
10
11
12
13
14

Figure 16. Wintertime average chlorides isopleths for waters of Jamaica Bay, g/l

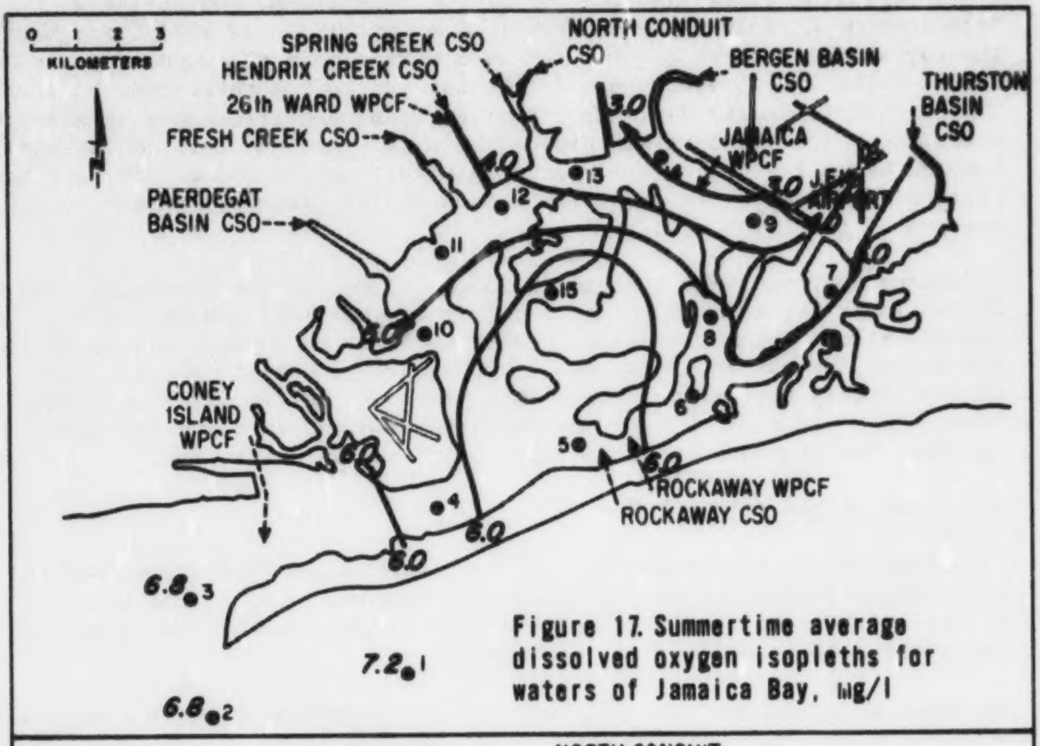

0 1 2 3
KILOMETERS
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
BERGEN BASIN CSO
26th WARD WPCF
THURSTON BASIN CSO
FRESH CREEK CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
3.0
4.0
5.0
6.0
6.8 3
7.2 1
6.8 2
4
5
6
7
8
9
10
11
12
13
15

Figure 17. Summertime average dissolved oxygen isopleths for waters of Jamaica Bay, mg/l

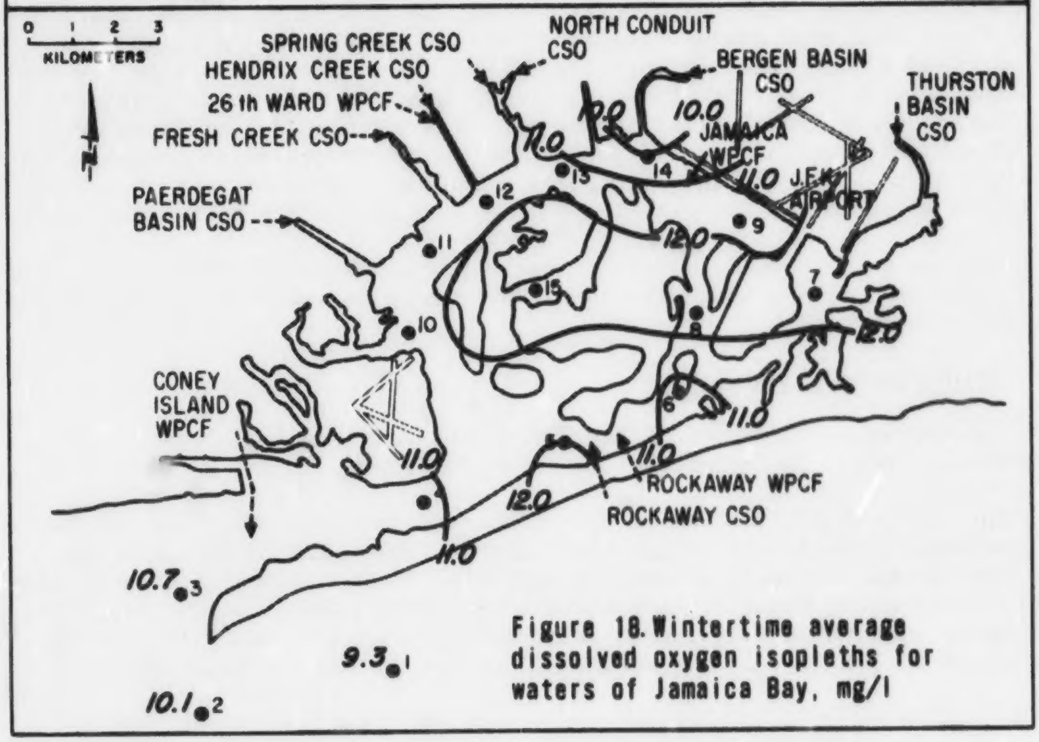

0 1 2 3
KILOMETERS
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
BERGEN BASIN CSO
26th WARD WPCF
THURSTON BASIN CSO
FRESH CREEK CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
10.0
11.0
12.0
10.7 3
9.3 1
10.1 2
6
7
8
9
10
11
12
13
14
15

Figure 18. Wintertime average dissolved oxygen isopleths for waters of Jamaica Bay, mg/l

which represent summertime and wintertime conditions, respectively. High average dissolved oxygen levels of around 10 to 12 mg/l throughout the bay in the wintertime are depressed markedly in the summertime to levels below 7 mg/l everywhere in the bay and to concentrations of less than 3 mg/l in Grassy Bay. The observed seasonal differences in average dissolved oxygen concentrations in Jamaica Bay are due both to seasonal temperature differences, which greatly affect oxygen solubility, and to seasonal differences in metabolic demand on the dissolved oxygen resources of the bay.

In Grassy Bay, vertical stratification of dissolved oxygen occurs, and in the lower layers of water zero values of dissolved oxygen may be found. Also, dramatic changes in dissolved oxygen content can occur throughout the day in Grassy Bay. Diurnal water quality characteristics of Grassy Bay are presented in Appendix E, Volume II, Supplemental Data. This behavior with respect to dissolved oxygen concentrations reflects the degraded water quality conditions in Grassy Bay.

Dissolved Oxygen Saturation--

Isopleths of average summertime and wintertime dissolved oxygen saturation values in Jamaica Bay are shown in Figures 19 and 20 and indicate generally the same spatial and seasonal distribution that was observed for average dissolved oxygen concentrations.

In Jamaica Bay proper, the minimum average wintertime dissolved oxygen saturation of about 94% occurred in the north channel in the vicinity of the 26th Ward sewage treatment facility discharge. A slightly depressed average wintertime value (96%) also occurred in Grassy Bay near the Jamaica sewage treatment facility outfall. Elsewhere in the bay during the wintertime, dissolved oxygen concentrations exceeded 100% due to photosynthetic activity of the large microplankton population in the bay. Lower average wintertime dissolved oxygen saturation values were noted in the Rockaway Inlet (98%) and in the New York Bight (94%).

Average summertime dissolved oxygen saturations were lowest (about 24%) in Grassy Bay and increased rather uniformly to values in excess of 80% in Rockaway Inlet.

Biochemical Oxygen Demand--

The spatial and seasonal distributions of summertime and wintertime average BOD_5 concentrations are shown in Figures 21 and 22.

The seasonal differences in BOD_5 concentrations are the result of the seasonal temperature differences; higher BOD_5 values occur in winter, when lower temperatures inhibit bacterial decomposition of organic matter, creating higher steady-state BOD_5 concentrations in the bay. Average summertime BOD_5 concentrations ranged from 1.6 mg/l in Rockaway Inlet to 3.6 mg/l in the center of the bay in Pumpkin Patch Channel.

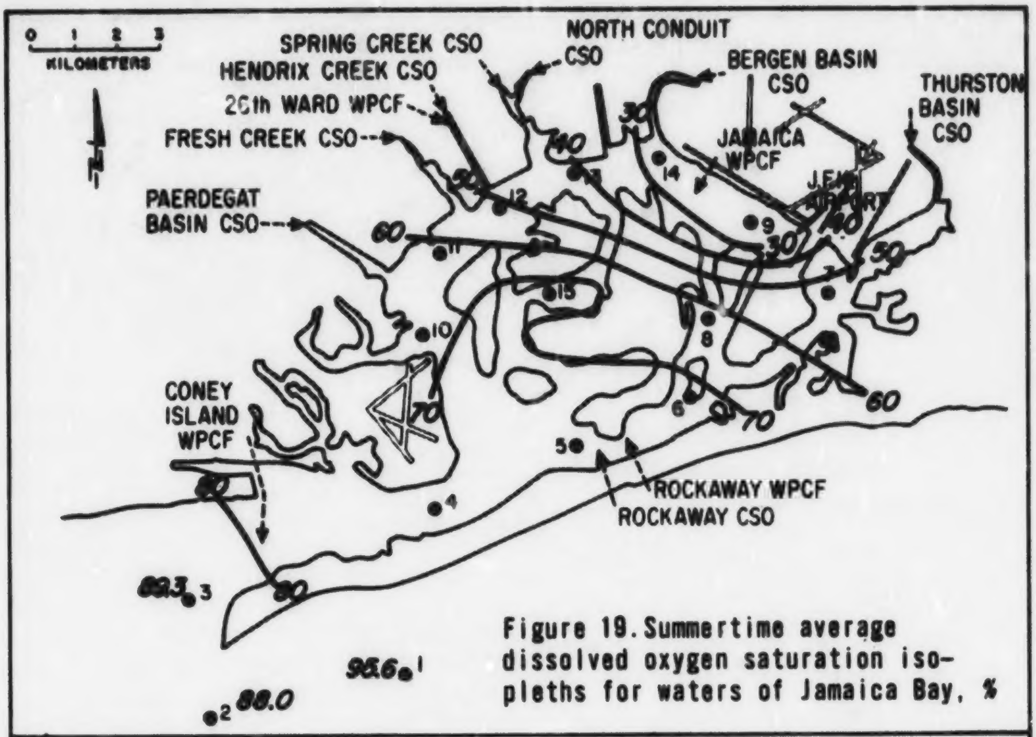

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
BERGEN BASIN CSO
26th WARD WPCF
THURSTON BASIN CSO
FRESH CREEK CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
40
30
50
60
70
80
89.3
95.6
88.0

Figure 19. Summertime average dissolved oxygen saturation isopleths for waters of Jamaica Bay, %

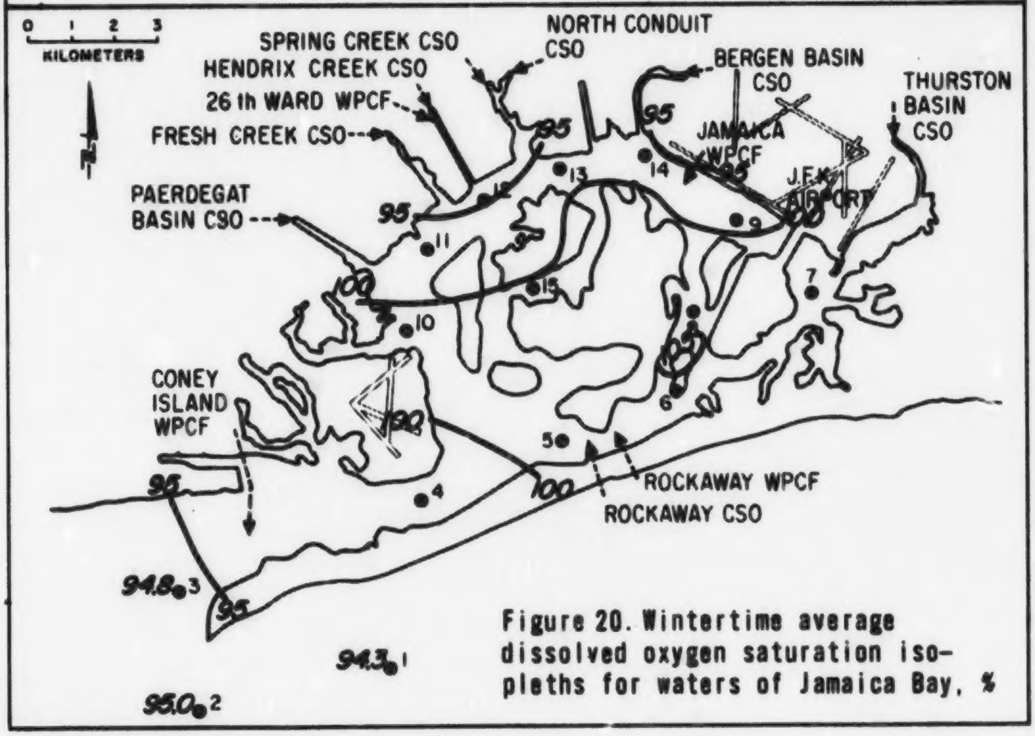
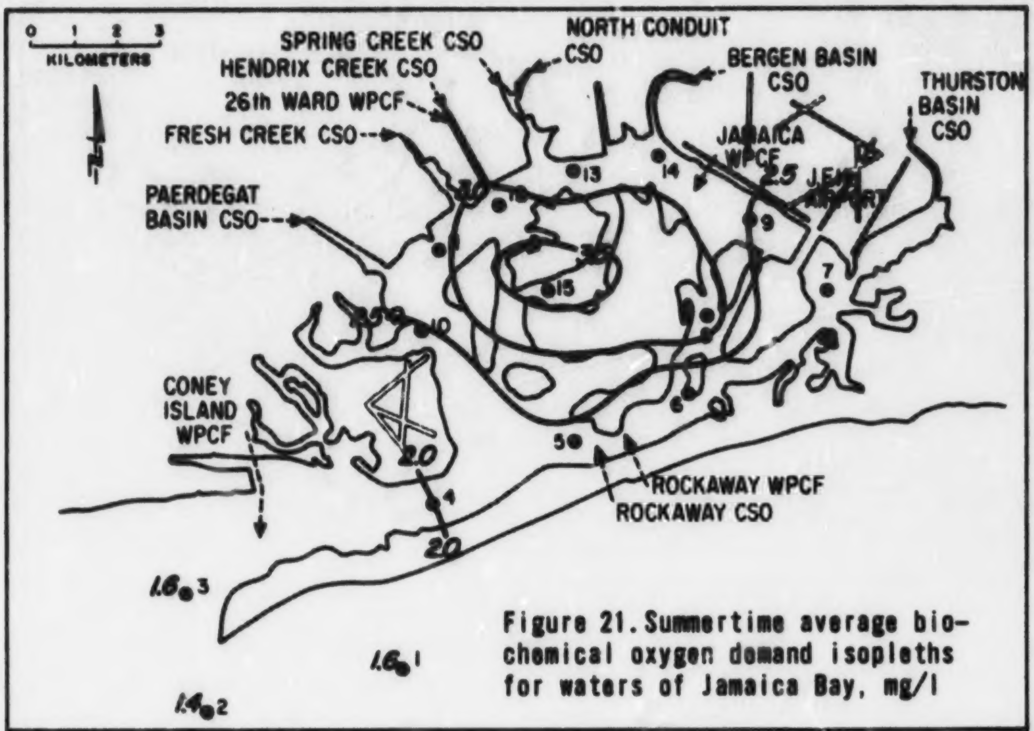

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
BERGEN BASIN CSO
26th WARD WPCF
THURSTON BASIN CSO
FRESH CREEK CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
95
90
100
94.8
94.3
95.0

Figure 20. Wintertime average dissolved oxygen saturation isopleths for waters of Jamaica Bay, %


0 1 2 3
KILOMETERS
N
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NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
13
14
3.0
12
2.5
9
3.5
15
7
2.5
10
8
6
5
2.0
4
2.0
1.6 3
1.6 1
1.4 2

Figure 21. Summertime average biochemical oxygen demand isopleths for waters of Jamaica Bay, mg/l

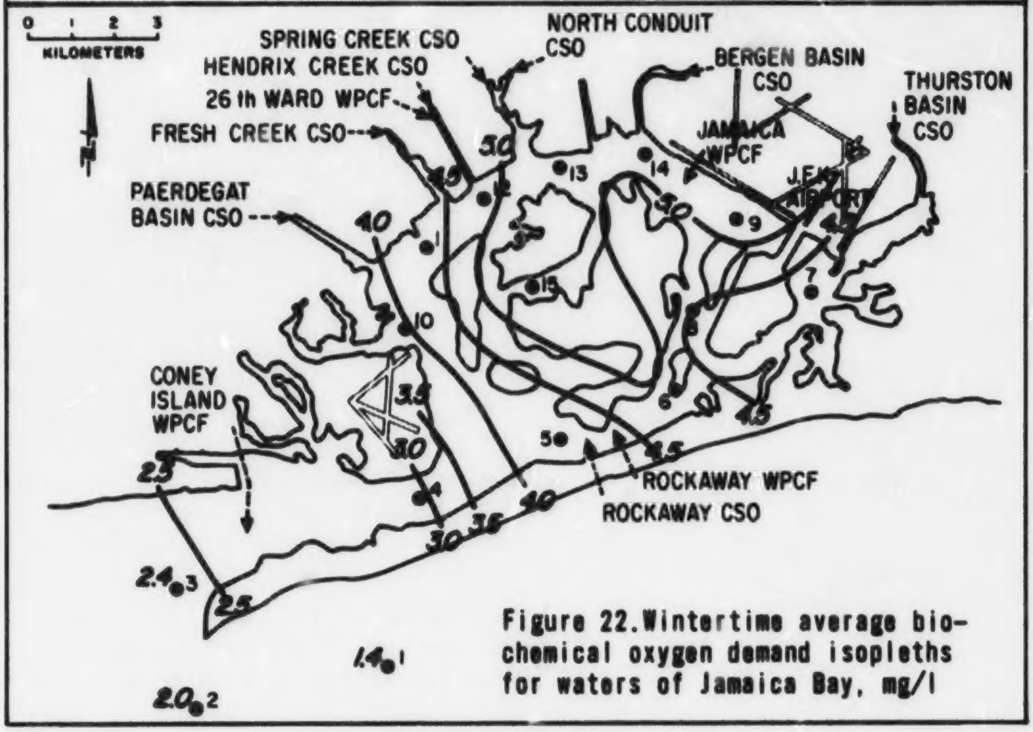

0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
5.0
13
14
4.5
12
5.0
4.0
9
4.5
1
15
7
10
8
3.5
6
4.5
3.0
5
3.5
2.5
4
4.0
3.0
3.5
2.4 3
2.5
1.4 1
2.0 2

Figure 22. Wintertime average biochemical oxygen demand isopleths for waters of Jamaica Bay, mg/l

Average wintertime BOD_5 concentrations ranged from 2.4 mg/l in Rockaway Inlet to 5.3 mg/l in Grassy Bay and in Pumpkin Patch Channel. The spatial differences in BOD_5 concentrations are the consequence primarily of wastewater and stormwater discharge locations. In general, the highest values, regardless of season, were observed in the vicinities of the 26th Ward and Jamaica sewage treatment facilities, discharging to the north channel and to Grassy Bay, respectively. Another significant source of oxidizable material is marsh grass which sloughs off into the bay.

Organic Nitrogen--

Average organic nitrogen concentrations in Jamaica Bay, shown for summertime and wintertime in Figures 23 and 24, respectively, generally increased in value from Rockaway Inlet toward the back of the bay at Grassy Bay and toward the proximity of sewage treatment facility discharges. This distribution would be expected because the two principal sources of organic nitrogen are wastewater effluents containing substantial amounts of unoxidized nitrogenous forms (proteins, nucleic acids, etc.) and cellular material (biomass), propagated in the receiving waters.

Average organic nitrogen levels seasonally were quite comparable and ranged from the low value of 0.45 mg/l at the mouth of Rockaway Inlet in the winter to the high value of 1.2 mg/l in Broad Channel during the summer. The slightly higher levels of organic nitrogen observed during the summer can be attributed to a rate of biological productivity of organic nitrogenous forms greater than the rate of bacterial decomposition.

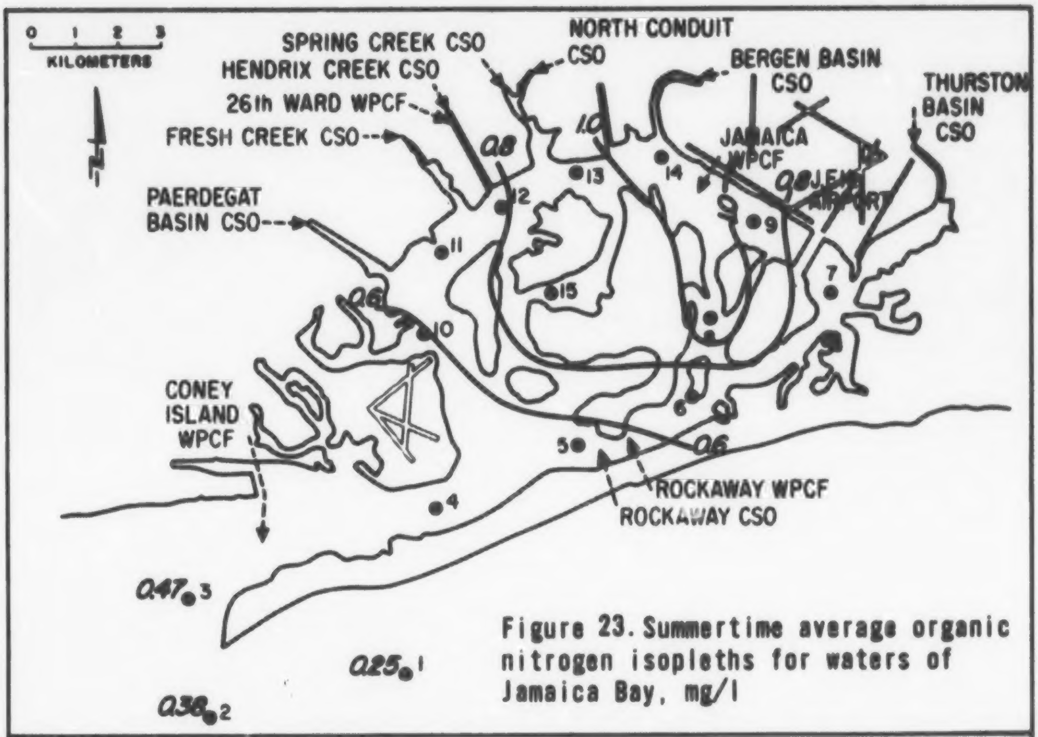
Ammonia--

Average summertime and wintertime ammonia nitrogen concentrations increased rather uniformly with distance from Rockaway Inlet to Grassy Bay, as shown in Figures 25 and 26. Summertime average ammonia concentrations ranged from about 0.2 to 1.2 mg/l, and wintertime averages ranged from around 0.4 to 1.8 mg/l. Higher ammonia levels in wintertime are probably due to the decreased metabolic conversion during the colder weather of ammonia discharged from the sewage treatment facilities.

The ammonia nitrogen concentrations throughout the bay and the year represent substantial amounts of ammonia for algal utilization. Thus ammonia appears not to be limiting with respect to biological growth.

Nitrate--

Average summertime nitrate concentrations, as shown in Figure 27, indicated very small spatial variances. The highest average concentrations, of 0.12 mg/l, were observed in the vicinity of the Rockaway sewage treatment facility. In the wintertime, average nitrate concentrations,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KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.8
1.0
0.8
0.6
0.6
12
13
14
9
11
15
7
10
6
5
4
0.47 3
0.25 1
0.38 2

Figure 23. Summertime average organic nitrogen isopleths for waters of Jamaica Bay, mg/l

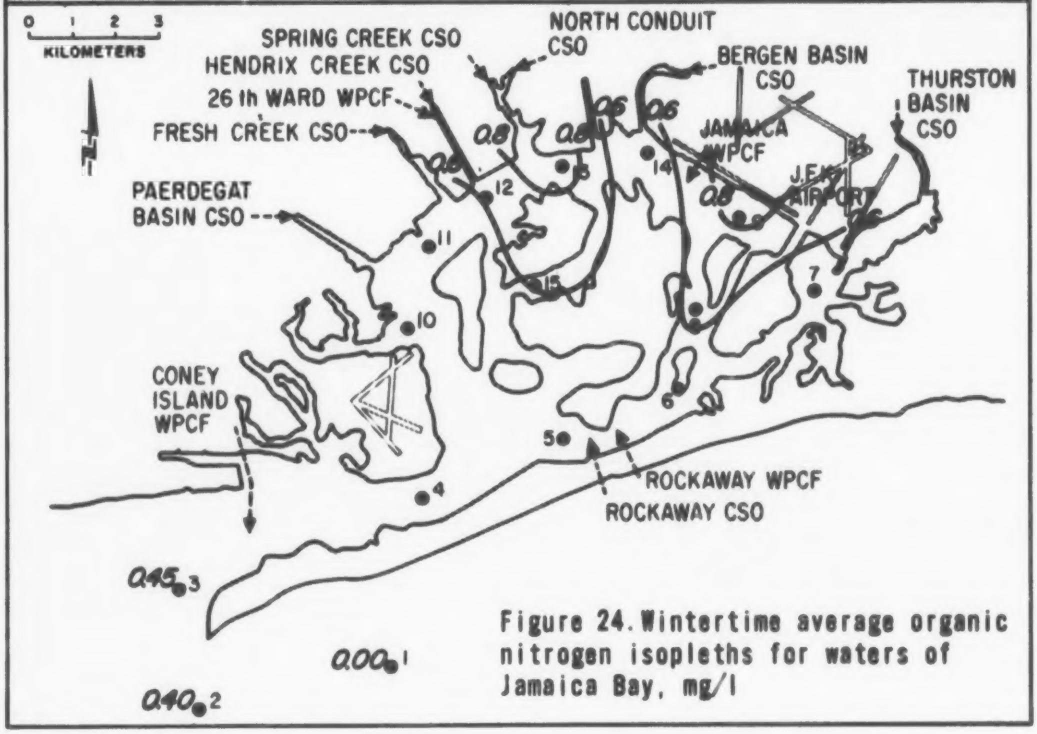
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.6
0.8
0.8
0.6
0.6
0.8
0.6
12
14
11
15
7
10
6
5
4
0.45 3
0.00 1
0.40 2

Figure 24. Wintertime average organic nitrogen isopleths for waters of Jamaica Bay, mg/l

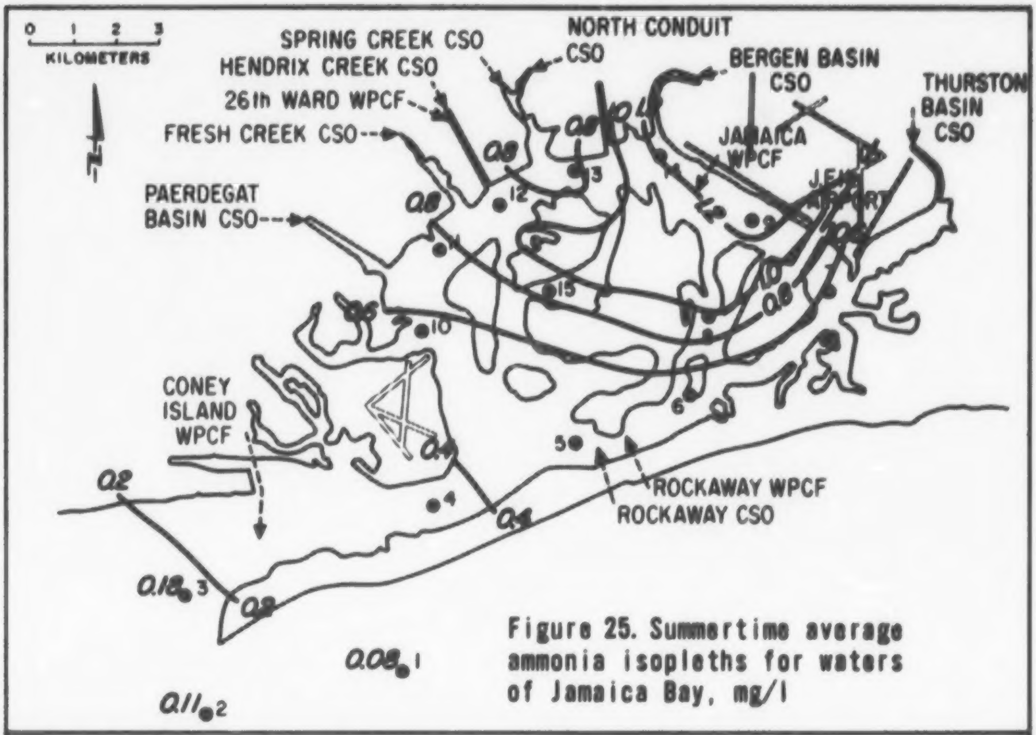
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
THURSTON BASIN CSO
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.8
0.8
0.8
1.0
1.2
1.0
0.8
0.6
0.4
0.4
0.2
0.2
0.18 3
0.08 1
0.11 2
12
13
15
10
4
5
6

Figure 25. Summertime average ammonia isopleths for waters of Jamaica Bay, mg/l

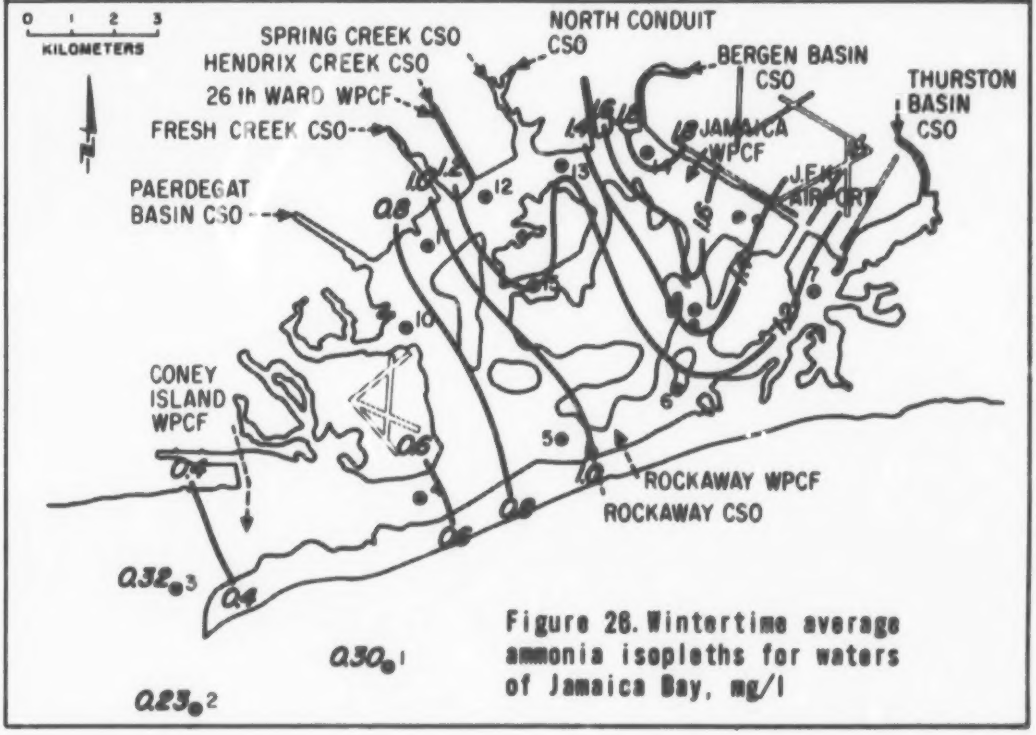
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
THURSTON BASIN CSO
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
1.0
1.2
0.8
1.4
1.6
1.5
1.8
1.5
1.4
1.2
1.0
0.8
0.6
0.6
0.4
0.4
0.32 3
0.30 1
0.23 2
12
13
15
10
5
6

Figure 26. Wintertime average ammonia isopleths for waters of Jamaica Bay, mg/l

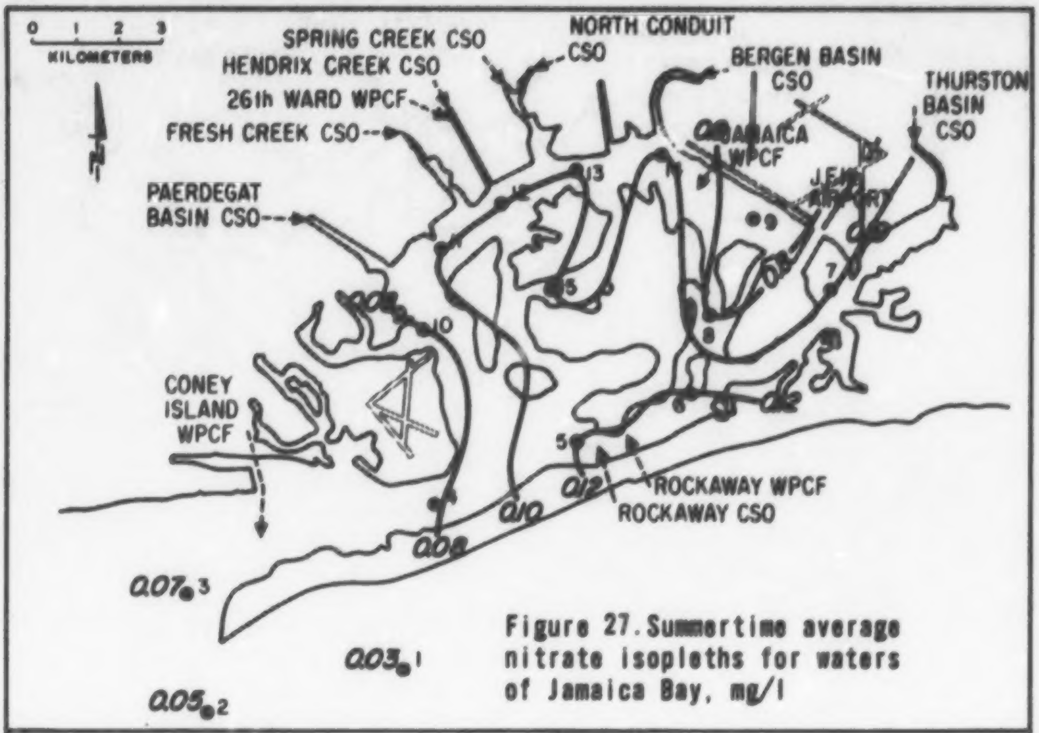
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.08
0.10
0.12
0.07 3
0.03 1
0.05 2
13
15
10
9
8
7
6
5
4

Figure 27. Summertime average nitrate isopleths for waters of Jamaica Bay, mg/l

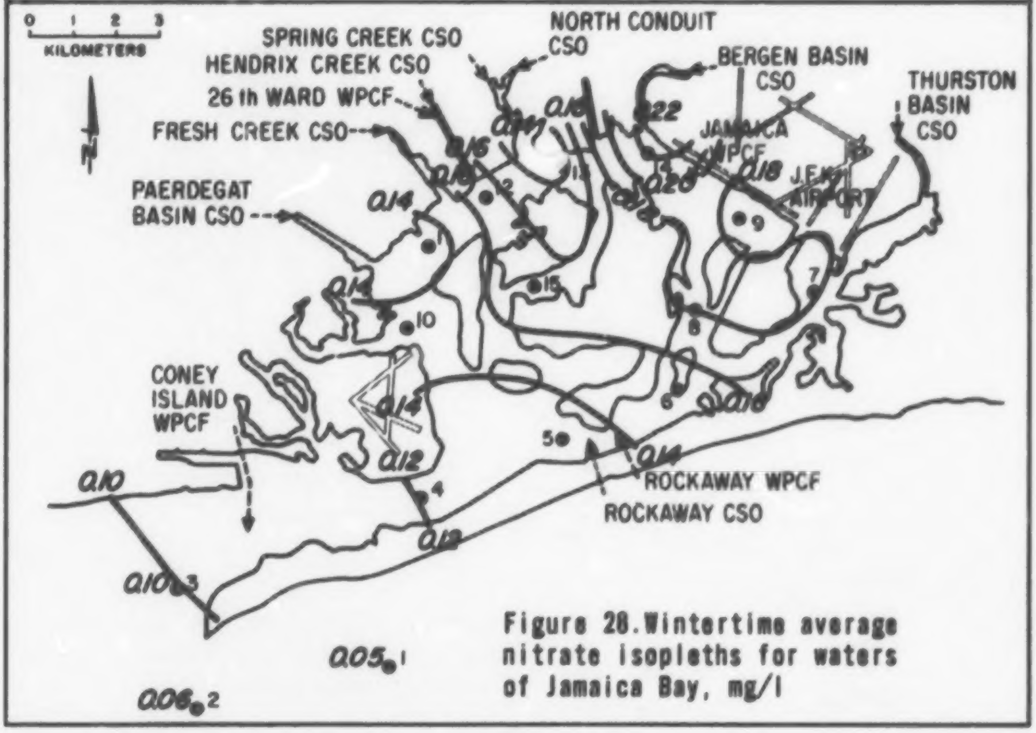
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.15
0.16
0.22
0.20
0.18
0.14
0.12
0.10
0.10 3
0.05 1
0.06 2
12
13
15
10
9
8
7
6
5
4

Figure 28. Wintertime average nitrate isopleths for waters of Jamaica Bay, mg/l

shown in Figure 28, indicated greater spatial differentiation, with the highest value, 0.22 mg/l, noted in Grassy Bay near the Jamaica sewage treatment facility discharge. Average nitrate values in the Rockaway Inlet and the New York Bight appeared to be slightly higher in the winter (0.05 to 0.10 mg/l) than in the summer (0.03 to 0.07 mg/l).

Adequate amounts of nitrate, independent of available ammonia concentrations, are apparently available at all times to support large algal populations.

Total Phosphate--

Concentration isopleths for total phosphate in the waters of Jamaica Bay are presented in Figures 29 and 30. While phosphate concentrations in the New York Bight are higher in wintertime, phosphate concentrations within the bay are for the most part rather seasonally independent. Spatial distributions of total phosphate within the bay are almost identical for both seasons, with concentrations of about 1 mg/l evident in the back-bay areas decreasing to values of around 0.2 mg/l in the Rockaway Inlet and the New York Bight.

Orthophosphate--

Patterns of distribution and variations of orthophosphate phosphorus in Jamaica Bay, as shown in Figures 31 and 32, closely follow those of total phosphate. There is a small, though distinct, increase in orthophosphates in wintertime over summertime concentrations; in both seasons a gradual rise in concentration is observed from the Rockaway Inlet to Grassy Bay.

Hexane Extractable Material--

Except for localized areas in Jamaica Bay, most concentrations of HEM are about equal in summertime and wintertime, as shown in Figures 33 and 34. Exceptionally high average local concentrations were observed in wintertime at Head of Bay south of the John F. Kennedy International Airport and at another point outside the bay in the New York Bight. High summertime average concentrations of HEM occurred in Pumpkin Patch Channel. With the exception of these high values, which might be expected due to the nature of the parameter, average HEM concentrations throughout the bay and the inlet were about 0.5 mg/l.

Total Coliforms--

Average total coliform densities were generally somewhat lower in summertime than in wintertime, as shown in Figures 35 and 36, respectively. The effects of the wastewater discharge from the 26th Ward sewage treatment facility are clearly in evidence, with average values in excess of 240 most probable number per milliliter (MPN/ml) indicated in the vicinity for both summertime and wintertime. In the summertime, average

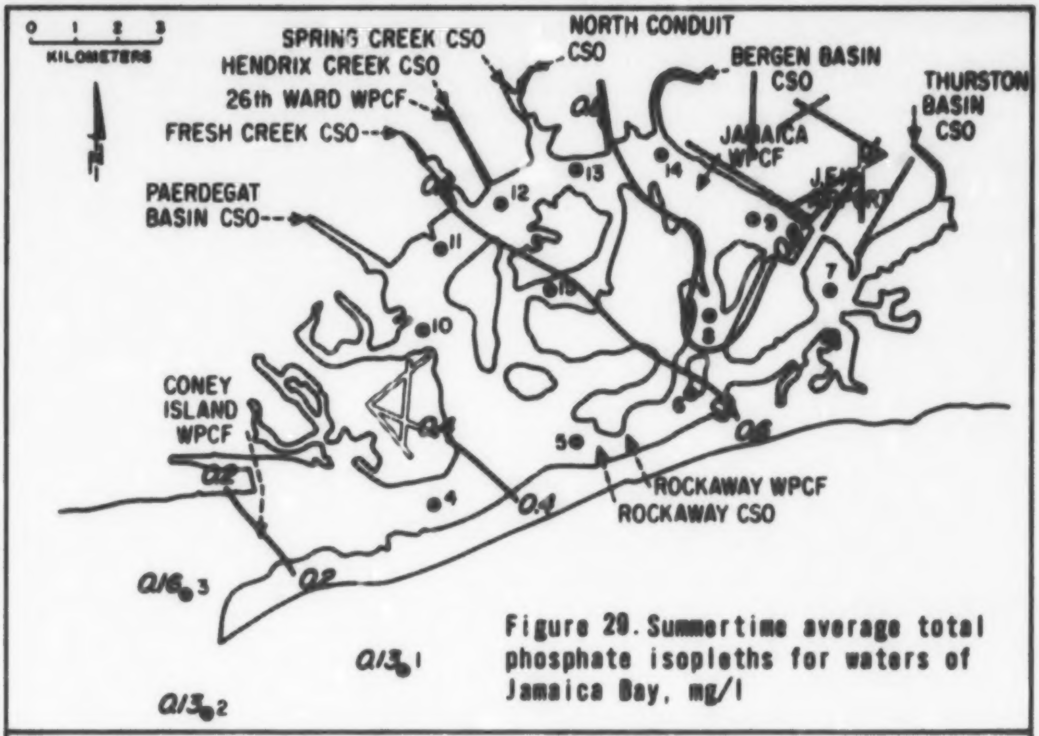
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.2
0.4
0.6
0.16 3
0.13 1
0.13 2
4
5
6
7
8
9
10
11
12
13
14
15

Figure 29. Summertime average total phosphate isopleths for waters of Jamaica Bay, mg/l

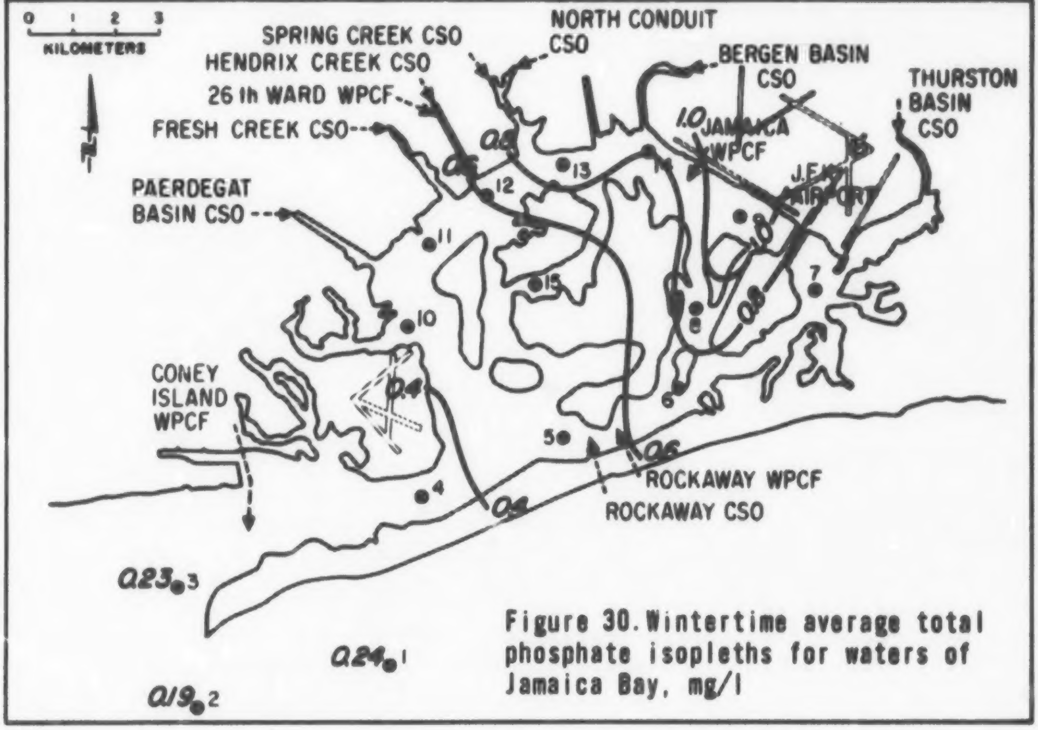
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26 th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
1.0
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.4
0.6
0.8
0.23 3
0.24 1
0.19 2
4
5
6
7
8
10
11
12
13
14
15

Figure 30. Wintertime average total phosphate isopleths for waters of Jamaica Bay, mg/l

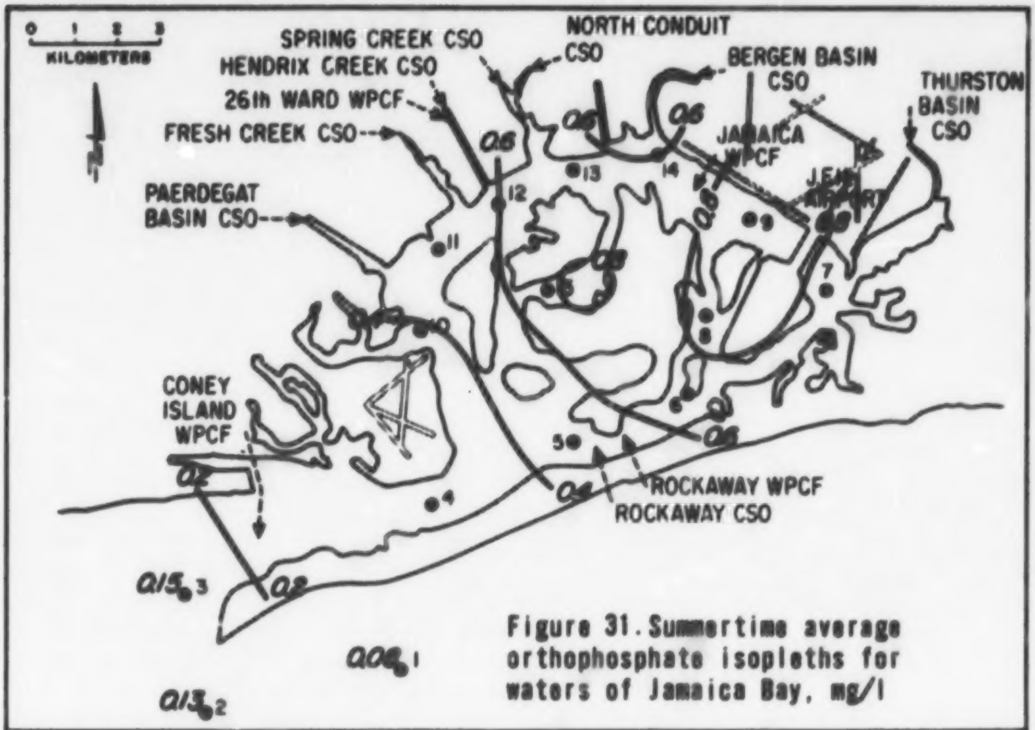
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.6
0.6
0.6
0.4
0.2
0.2
12
13
14
11
10
9
7
6
5
4
0.15 3
0.08 1
0.13 2

Figure 31. Summertime average orthophosphate isopleths for waters of Jamaica Bay, mg/l

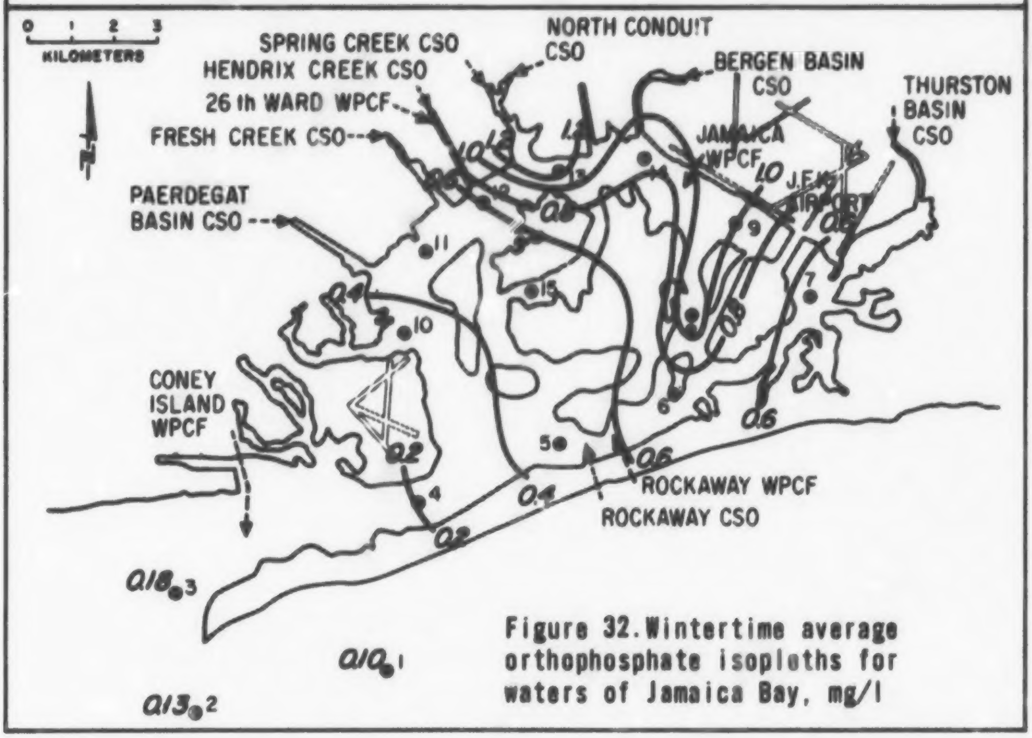
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
1.2
1.2
1.0
1.0
0.8
0.8
0.8
0.6
0.6
0.6
0.4
0.4
0.2
0.2
15
11
10
9
7
6
5
4
0.18 3
0.10 1
0.13 2

Figure 32. Wintertime average orthophosphate isopleths for waters of Jamaica Bay, mg/l

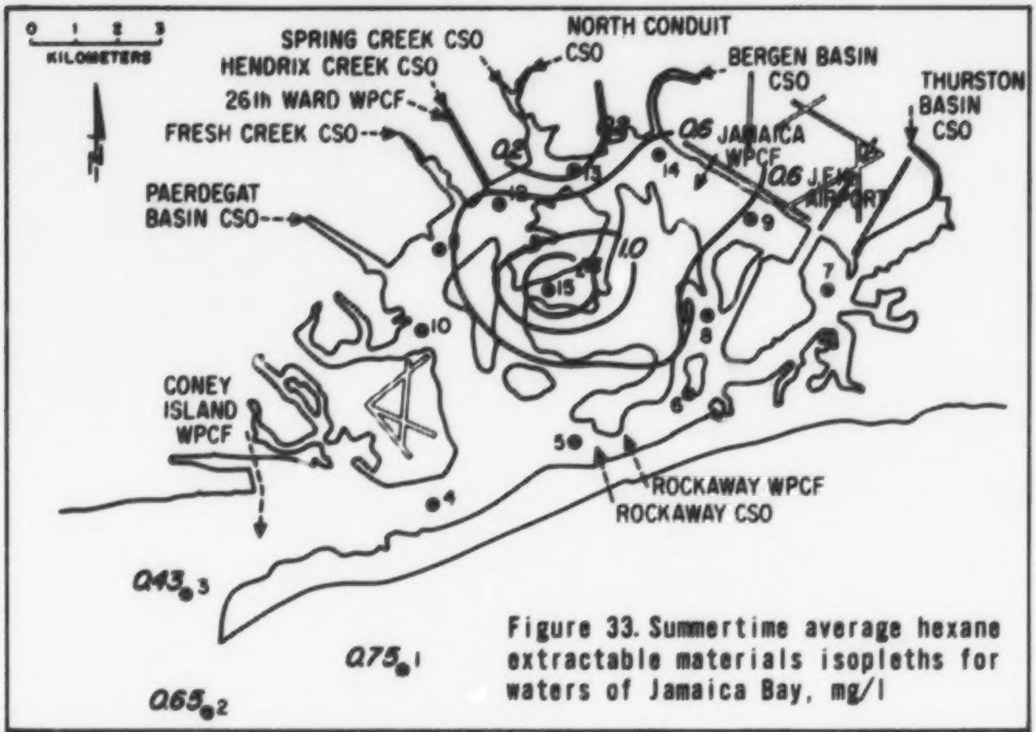
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.5
0.6
0.6
1.0
12
13
14
9
15
7
10
8
6
5
4
0.43 3
0.75 1
0.65 2

Figure 33. Summertime average hexane extractable materials isopleths for waters of Jamaica Bay, mg/l

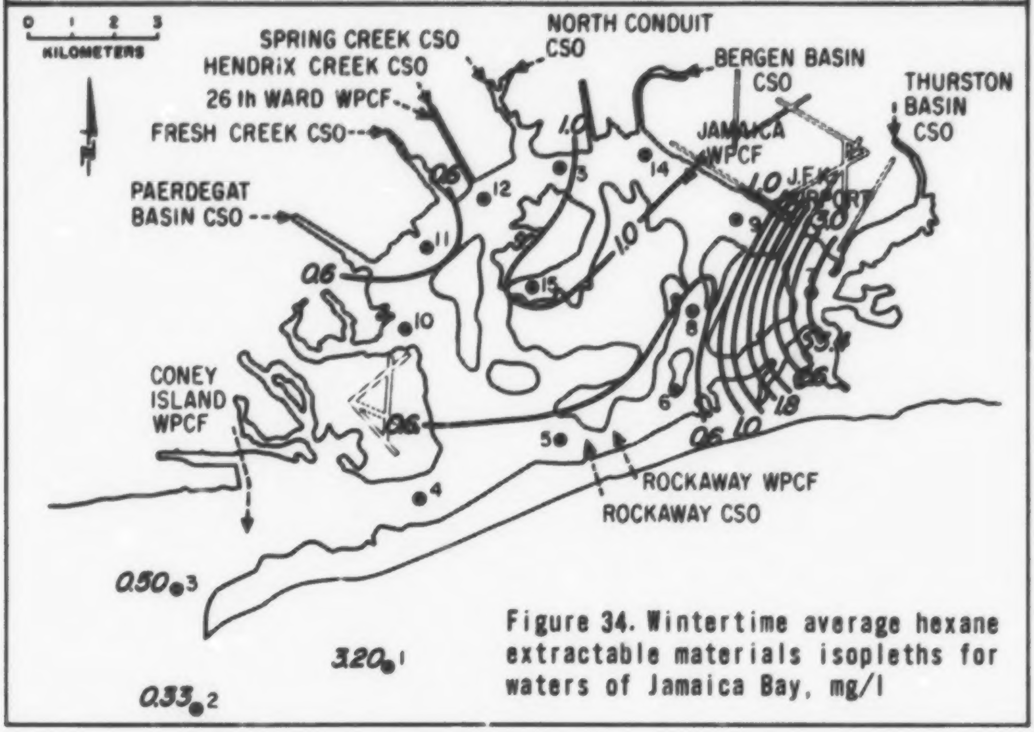
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
1.0
0.5
1.0
0.6
1.0
3.0
0.6
1.8
0.6
1.0
0.6
12
13
14
11
9
15
10
8
6
5
4
0.50 3
3.20 1
0.33 2

Figure 34. Wintertime average hexane extractable materials isopleths for waters of Jamaica Bay, mg/l

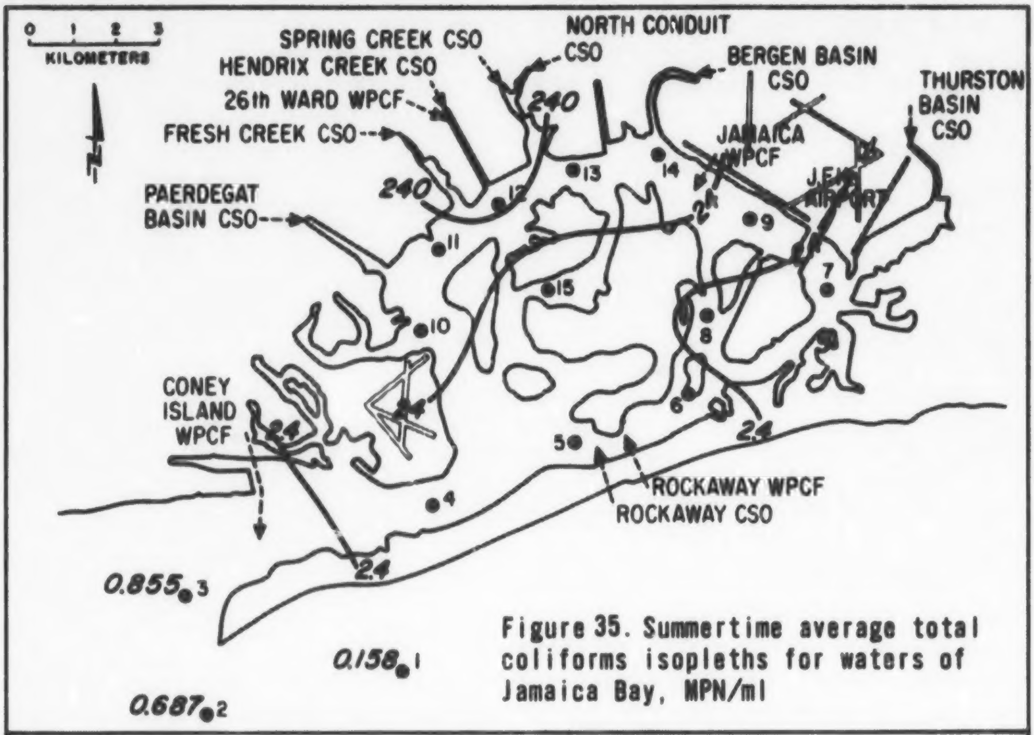
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
240
240
24
24
24
24
24
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
0.855
0.158
0.687

Figure 35. Summertime average total coliforms isopleths for waters of Jamaica Bay, MPN/ml

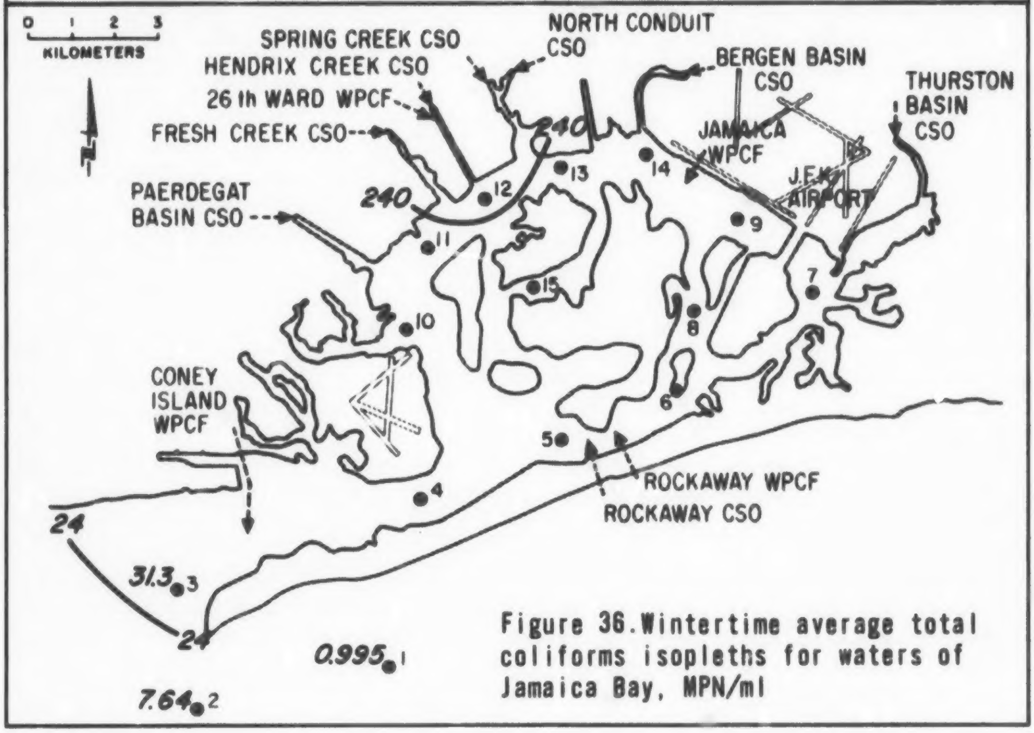
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
240
240
24
24
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
31.3
0.995
7.64

Figure 36. Wintertime average total coliforms isopleths for waters of Jamaica Bay, MPN/ml

total coliform concentrations were in excess of bathing water standards of 24 MPN/ml throughout the north channel of the bay. In the wintertime, average concentrations of total coliforms were in excess of the water contact standards of 24 MPN/ml everywhere in Jamaica Bay.

Fecal Coliforms--

Fecal coliform densities were considerably higher in wintertime than in summertime, as shown in Figures 37 and 38. Just as with total coliforms, fecal coliforms increase inward from the New York Bight to the vicinity of the 26th Ward sewage treatment facility.

Fecal Streptococci--

The same temporal and spatial distributions which were observed for fecal coliforms apply to streptococcal concentrations, as seen from Figures 39 and 40. Concentrations of fecal streptococci, although more uniform throughout the bay, were highest in the north channel in the vicinity of the 26th Ward sewage treatment facility.

Microplankton--

Average summertime and wintertime microplankton concentrations in Jamaica Bay are shown in Figures 41 and 42, respectively. Summertime average microplankton concentrations decreased from maximum values of about 700 organisms per milliliter (org/ml) in Rockaway Inlet to a minimum average of around 80 org/ml in the north channel between the Paerdegat Basin and Fresh Creek Basin combined sewer overflows. Average summertime values throughout the remainder of the bay ranged between 90 and 180 org/ml, with the exception of a higher average value of 270 org/ml in Beach Channel.

Wintertime average microplankton concentrations, on the contrary, generally increased from low values of around 7,000 org/ml in Rockaway Inlet to a high value of nearly 27,000 org/ml in Broad Channel.

Microplankton Diversity--

Summertime average microplankton species diversity indices in Jamaica Bay, presented in Figure 43, indicated values ranging from 0.32 in the north channel between Paredegat Basin and Fresh Creek Basin combined sewer overflows to 1.03 in Beach Channel in the immediate vicinity of the Rockaway sewage treatment facility discharge. Average summertime values in Rockaway Inlet and the New York Bight ranged from 0.82 to 0.91, respectively.

Average wintertime microplankton species diversity indices, shown on Figure 44, were substantially less than summertime averages. The lowest value, 0.13, was noted in Grassy Bay near the Bergen Basin combined sewer overflow and in the north channel between Paerdegat Basin and Fresh Creek Basin combined sewer overflows. The highest value, 0.29,

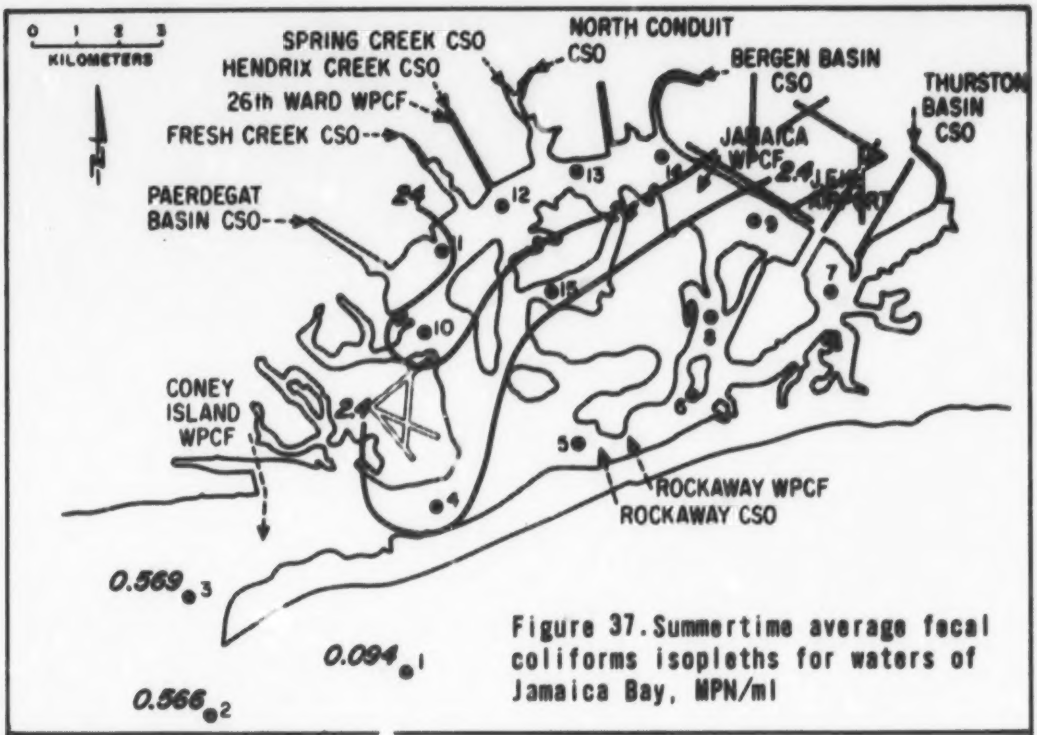
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
24
24
24
2.4
1
4
5
6
7
8
9
10
11
12
13
14
15
0.569 3
0.094 1
0.566 2

Figure 37. Summertime average fecal coliforms isopleths for waters of Jamaica Bay, MPN/ml

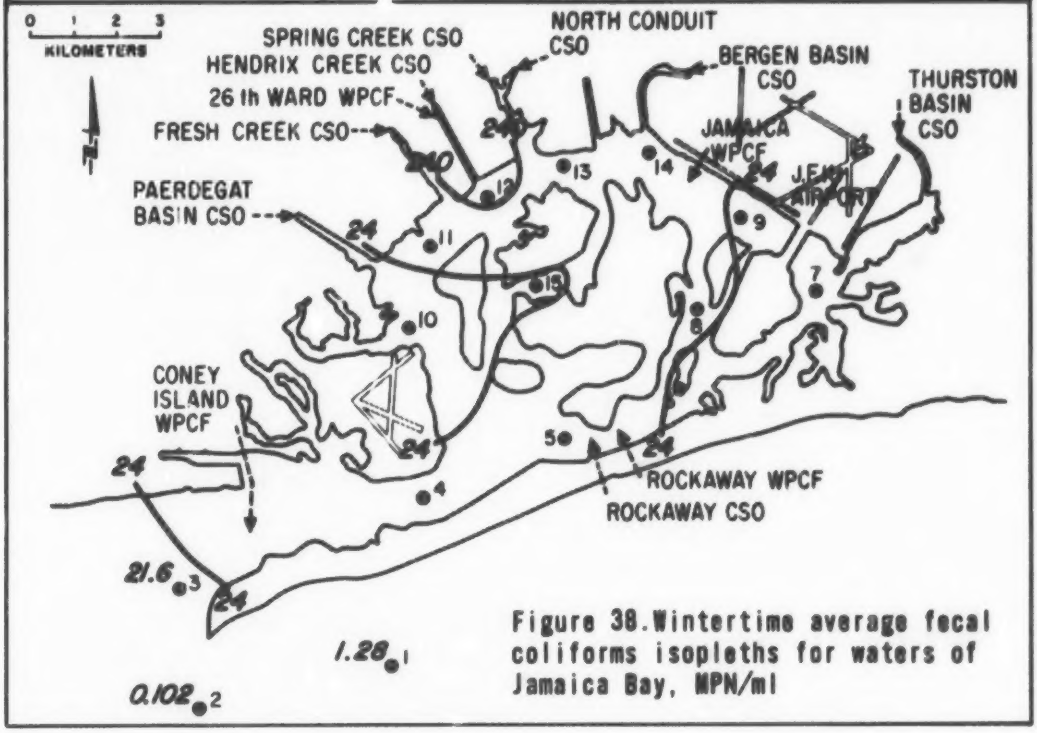
0 1 2 3
KILOMETERS
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
240
240
24
24
24
24
24
24
4
5
7
8
9
10
11
12
13
14
15
21.6 3
1.28 1
0.102 2

Figure 38. Wintertime average fecal coliforms isopleths for waters of Jamaica Bay, MPN/ml

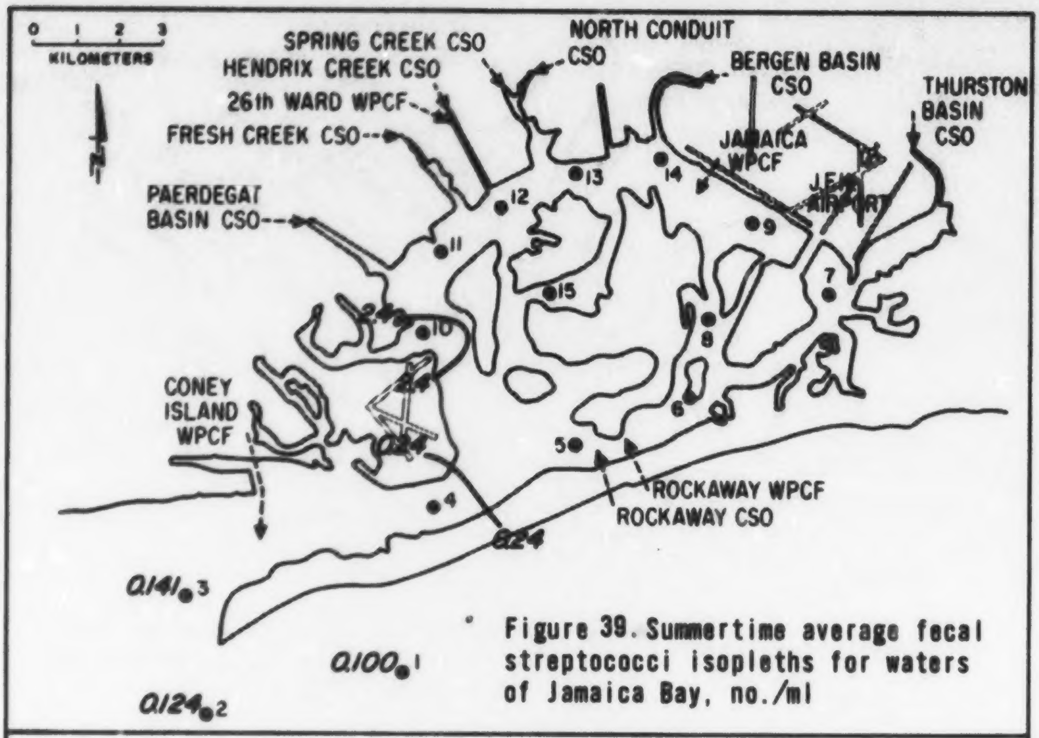
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
2.4
0.24
0.24
0.141 3
0.100 1
0.124 2
4
5
6
7
8
9
10
11
12
13
14
15

Figure 39. Summertime average fecal streptococci isopleths for waters of Jamaica Bay, no./ml

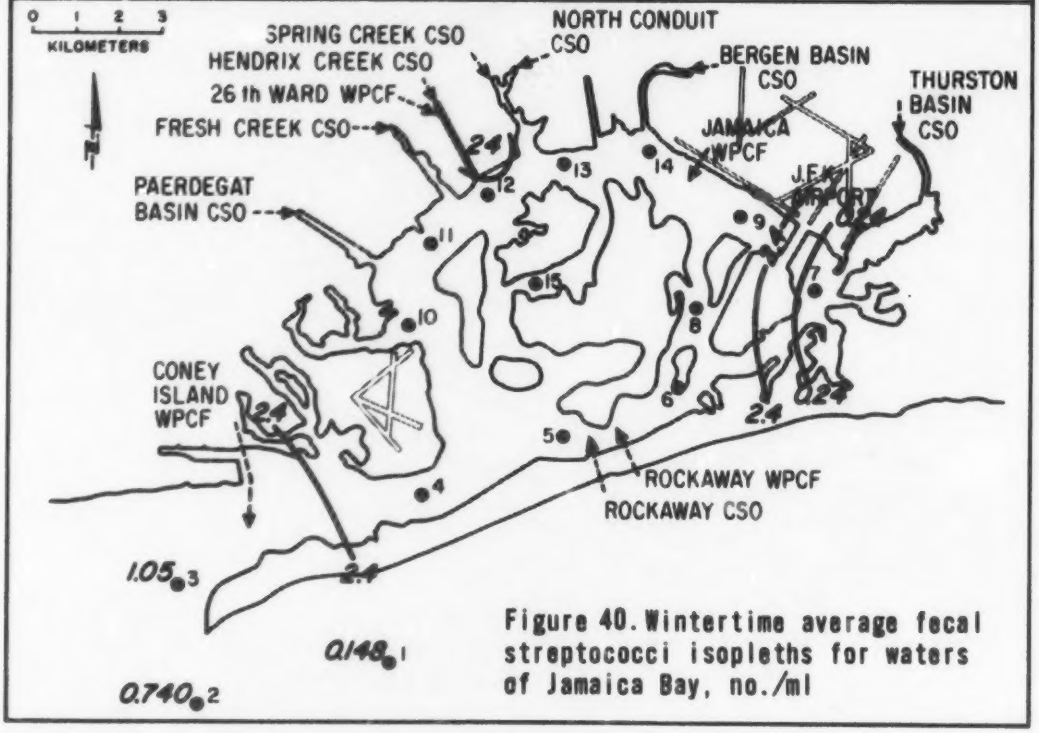
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
24
2.4
2.4
2.4
0.24
1.05 3
0.148 1
0.740 2
4
5
6
7
8
9
10
11
12
13
14
15

Figure 40. Wintertime average fecal streptococci isopleths for waters of Jamaica Bay, no./ml

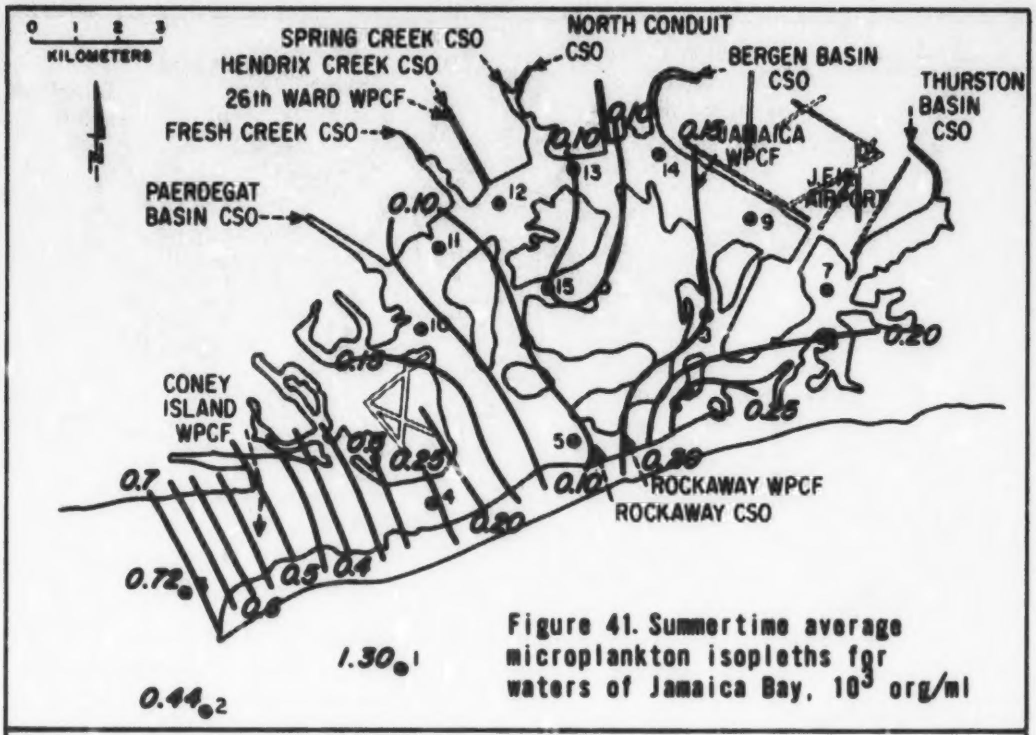
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.10
0.10
0.10
0.15
0.15
0.10
0.15
0.25
0.20
0.25
0.20
0.10
0.20
0.7
0.6
0.5
0.4
0.72
1.30
0.44
1
2
3
4
5
7
9
10
11
12
13
14
15

Figure 41. Summertime average microplankton isopleths for waters of Jamaica Bay, 10^3 org/ml

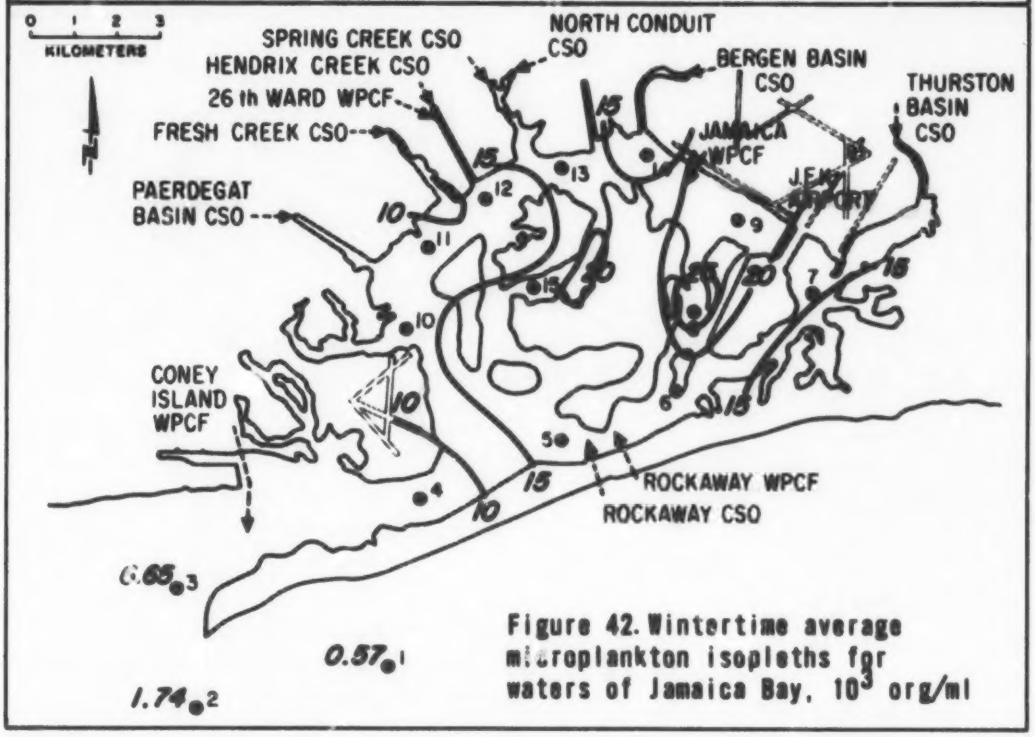
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
15
15
10
20
25
20
15
15
10
15
10
0.65
0.57
1.74
1
2
3
4
5
6
7
9
10
11
12
13
15

Figure 42. Wintertime average microplankton isopleths for waters of Jamaica Bay, 10^3 org/ml

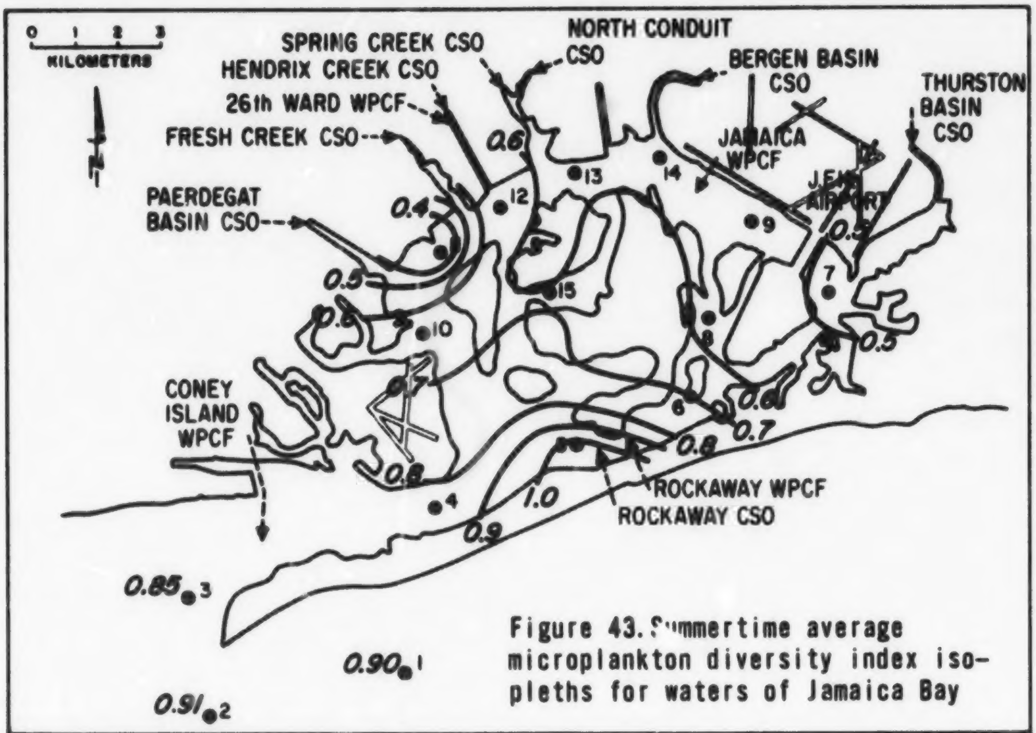
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.6
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0.8
0.7
0.6
0.5
0.5
12
13
14
9
7
15
10
8
6
5
4
0.85 3
0.90 1
0.91 2

Figure 43. Summertime average microplankton diversity index isopleths for waters of Jamaica Bay

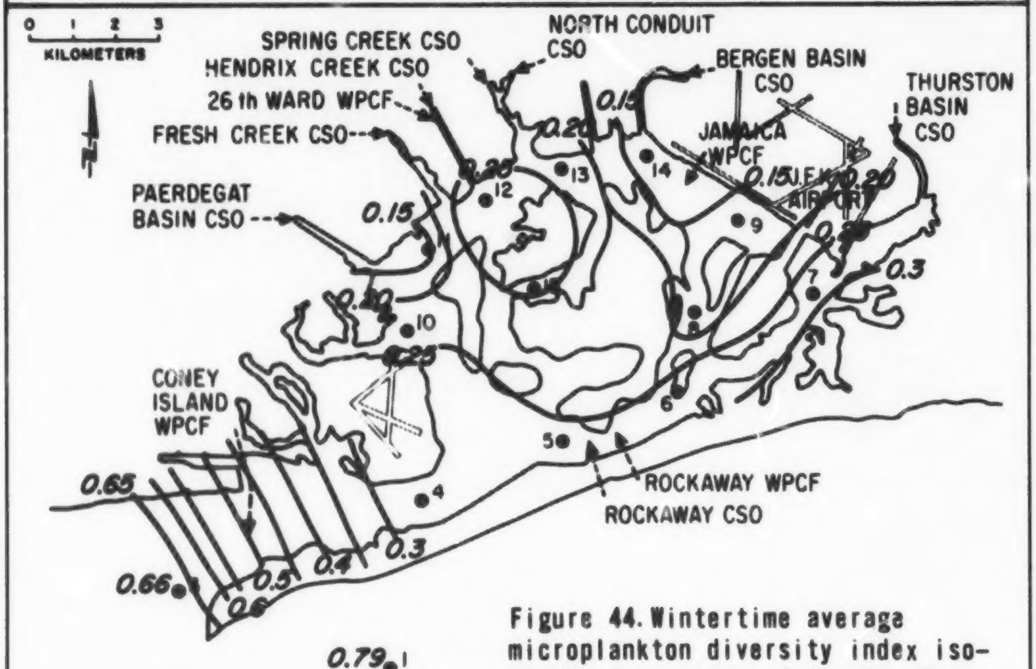
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.15
0.20
0.20
0.15
0.15
0.20
0.20
0.25
0.3
0.20
0.25
0.65
0.3
0.4
0.5
0.6
12
13
14
9
7
15
10
8
6
5
4
0.66 3
0.79 1
0.79 2

Figure 44. Wintertime average microplankton diversity index isopleths for waters of Jamaica Bay

in Jamaica Bay was observed in Head of Bay. Wintertime averages in Rockaway Inlet and the New York Bight ranged from 0.66 to 0.79, respectively.

Zooplankton--

Average summertime zooplankton concentrations in Jamaica Bay, shown in Figure 45, ranged from a high value of greater than 83 organisms per liter (org/l) observed in Pumpkin Patch Channel in the middle of the bay to a low value of around 13 org/l in Rockaway Inlet. Larger average zooplankton concentrations (more than 75 org/l) were noted in Beach Channel in the vicinity of the Rockaway sewage treatment facility than in Head of Bay, where the average value was about 36 org/l. Zooplankton concentrations in the New York Bight were generally less, ranging from about 11 to 46 org/l.

As shown in Figure 46, wintertime average zooplankton concentrations were an order of magnitude less than summertime averages. In general, they decreased in value from about 6 org/l in Rockaway Inlet, Island Channel and Pumpkin Patch Channel to less than 2 org/l in Head of Bay and less than 3 org/l in Grassy Bay. Average concentrations in the New York Bight in the wintertime were in the range of 5 to 6 org/l.

Neither summertime nor wintertime zooplankton populations appeared to correlate with sewage treatment facility discharge or combined sewer overflow locations.

Zooplankton Diversity--

Spatial and seasonal distributions of zooplankton species diversity indices are shown for summertime in Figure 47 and for wintertime in Figure 48. Whereas the lowest diversities (about 0.85) were observed in Grassy Bay and Rockaway Inlet during the summertime, the lowest (about 0.71) occurred in the wintertime in the north channel in the proximity of the 26th Ward sewage treatment facility discharge.

In general, the summertime zooplankton diversities in the bay were comparable to those in the New York Bight, where they ranged between 0.78 and 1.04; wintertime diversities were all higher in the bay, ranging from 1.2 to 0.71, as compared to values of around 0.55 reported for the New York Bight. All of these species diversity indices are representative of healthy zooplankton communities.

Sediment Quality

Unlike water quality, where generally distinct seasonal variations occur, sediment quality is more stable with respect to time. As a result, characteristics of the sediments in Jamaica Bay, obtained from the 3-yr sampling and analysis effort, have been averaged without reference to season. Detailed results are presented in Appendix F, Volume II, Supplemental Data.

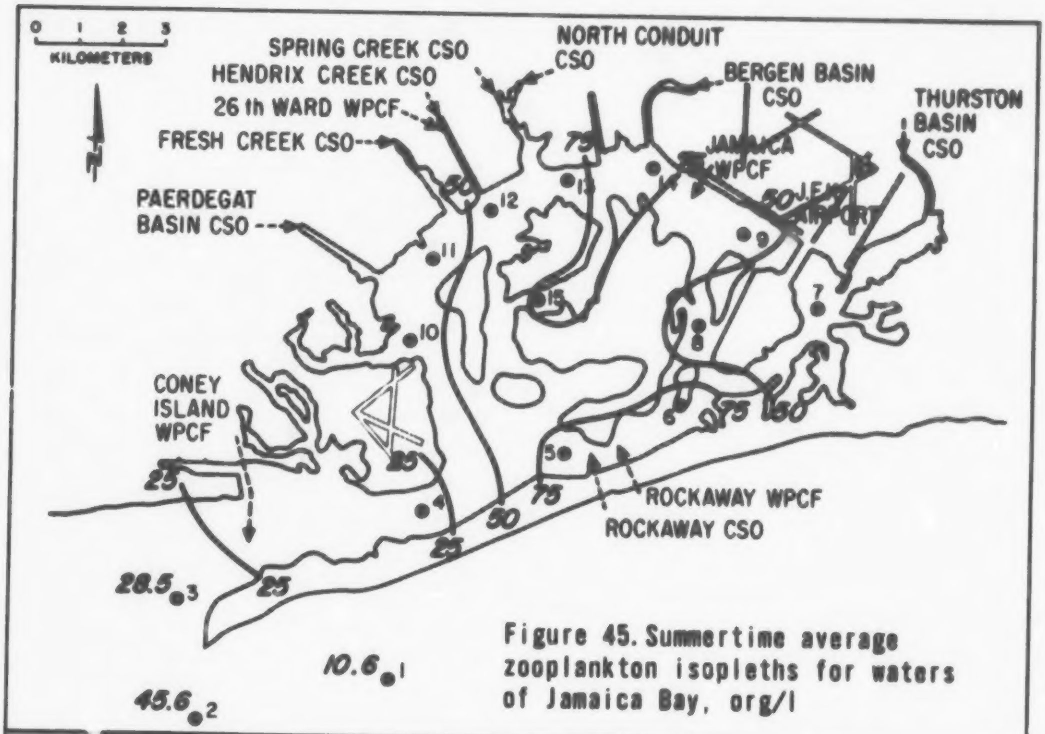
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
75
50
25
28.5 3
10.6 1
45.6 2

Figure 45. Summertime average zooplankton isopleths for waters of Jamaica Bay, org/l

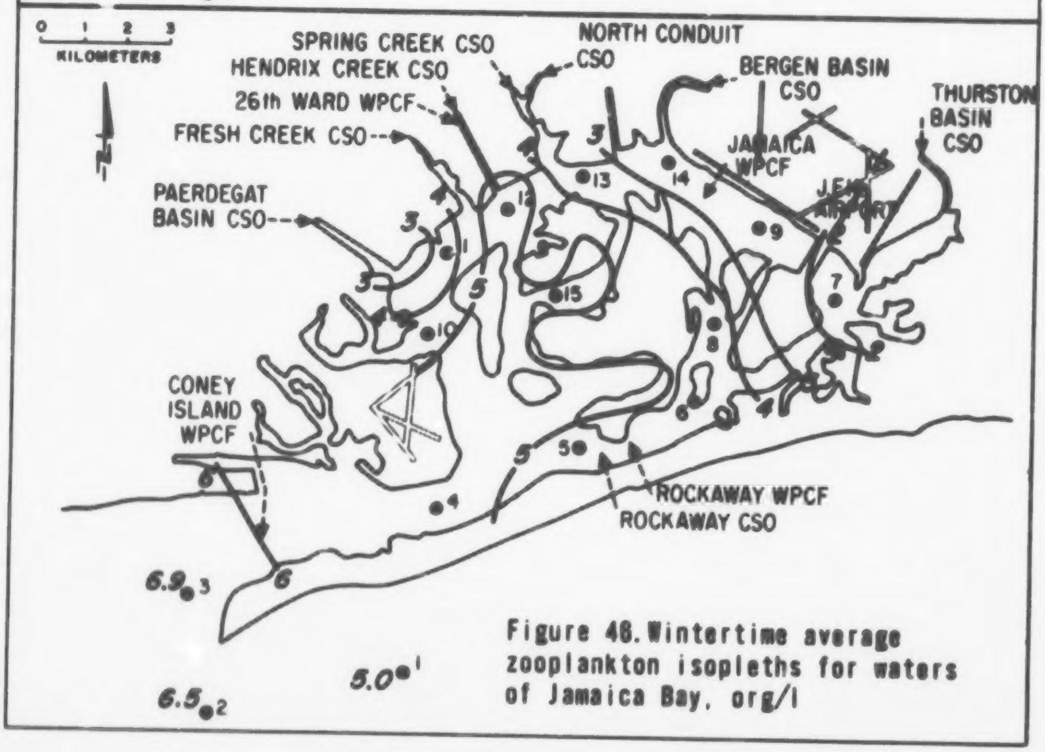
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
3
4
5
6
6.9 3
5.0 1
6.5 2

Figure 46. Wintertime average zooplankton isopleths for waters of Jamaica Bay, org/l

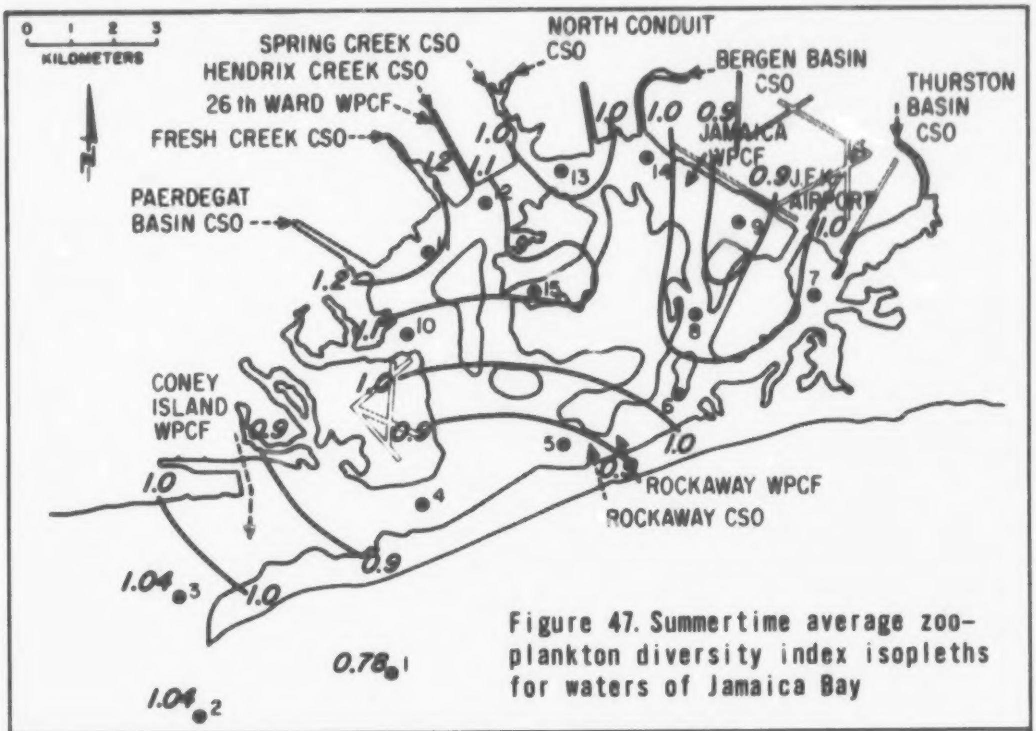
0 1 2 3
KILOMETERS
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
1.0
1.2
1.1
0.9
1.04
0.78
1.04

Figure 47. Summertime average zooplankton diversity index isopleths for waters of Jamaica Bay

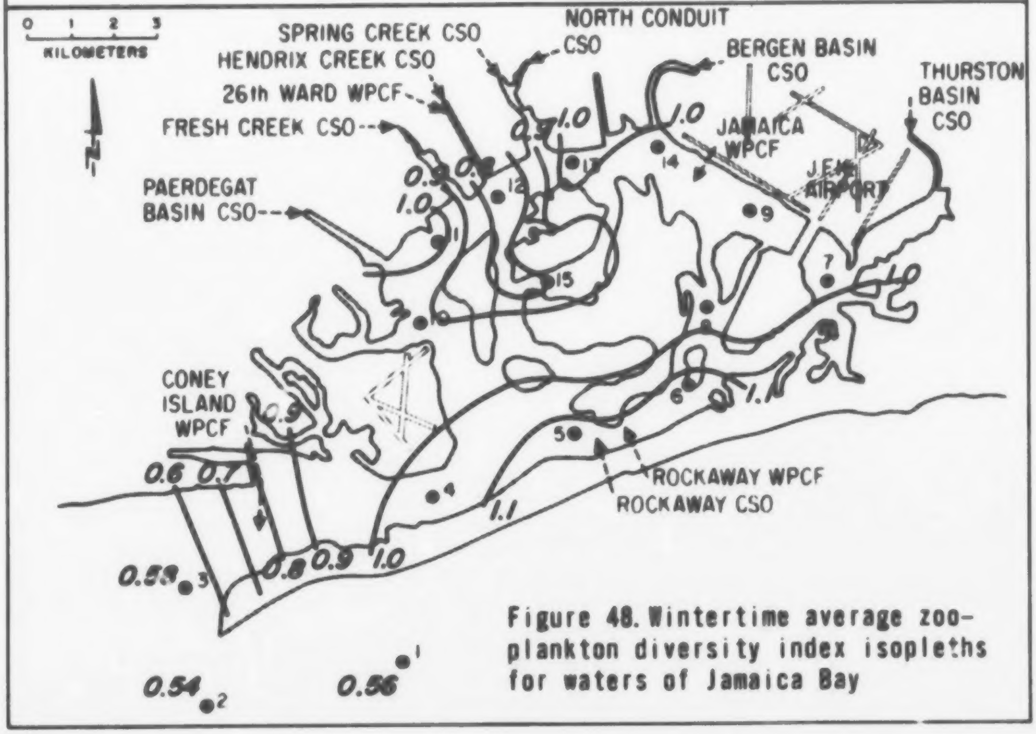
0 1 2 3
KILOMETERS
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.6
0.7
0.8
0.9
1.0
1.1
0.58
0.54
0.56

Figure 48. Wintertime average zooplankton diversity index isopleths for waters of Jamaica Bay

Temperature--

A slight and very gradual increase in average sediment temperature, from about 11°C at Rockaway Inlet to about 13°C in Grassy Bay, was observed, as shown in Figure 49.

Biochemical Oxygen Demand--

Sediment BOD_5 distribution is very distinct in pattern and varies considerably from that of the overlying water distributions. As shown in Figure 50, minimum sediment BOD_5 concentrations of less than 2 milligrams per gram (mg/g) occur in Rockaway Inlet and increase in either direction toward Canarsie Beach on the west and Head of Bay on the east. Maximum average concentrations of sediment BOD_5 greater than 12 mg/g were observed in Head of Bay.

Dry Solids--

Percentage dry solids, which is the inverse of moisture content, is a crude physical measure of sediments which reflects their moisture-bearing property. Values in excess of 60% indicate high sand content with some or little organic material. Values below 40% are indicative of sludge deposits.

The average dry solids content of the sediments in Jamaica Bay is shown in Figure 51. In Rockaway Inlet and in much of the central bay, the dry solids content was in excess of 70%. Sediments in Head of Bay and Grassy Bay indicated dry solids content of less than 40%.

Sand--

Average sand content of sediments, shown in Figure 52, parallels average dry solids content. Average sand content increases from about 80% in Rockaway Inlet to values less than 40% in Grassy Bay and Head of Bay.

Silt--

The distribution of average silt content of sediments in Jamaica Bay, shown in Figure 53, is relatively uniform throughout the channels of the bay but increases from about 10% there to over 30% in the northern portion of Grassy Bay.

Clay--

Average clay content variations in the Jamaica Bay sediments, as shown in Figure 54, are consistent with other sediment physical characteristics. The clay fraction of the sediments increases from values of less than 10% in the Rockaway Inlet to values of 50% in Grassy Bay.

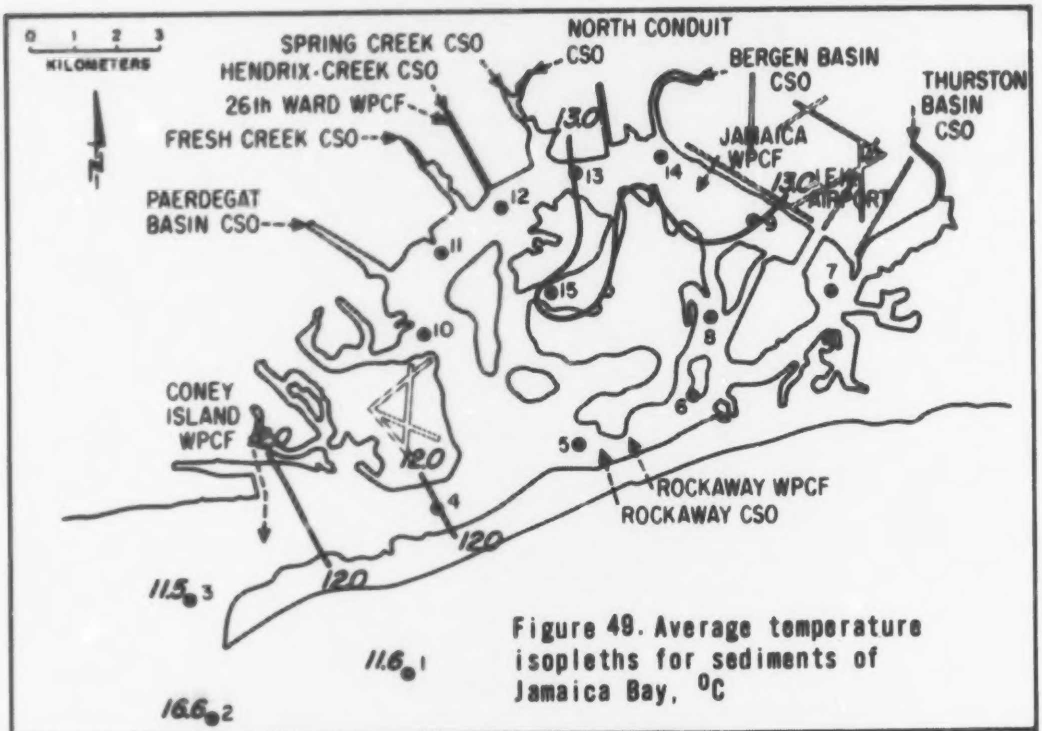
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX-CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
THURSTON BASIN CSO
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
13.0
13.0
12.0
12.0
12.0
12.0
12.0
11.5 3
11.6 1
16.6 2
4
5
6
7
8
9
10
11
12
13
14
15

Figure 49. Average temperature isopleths for sediments of Jamaica Bay, °C

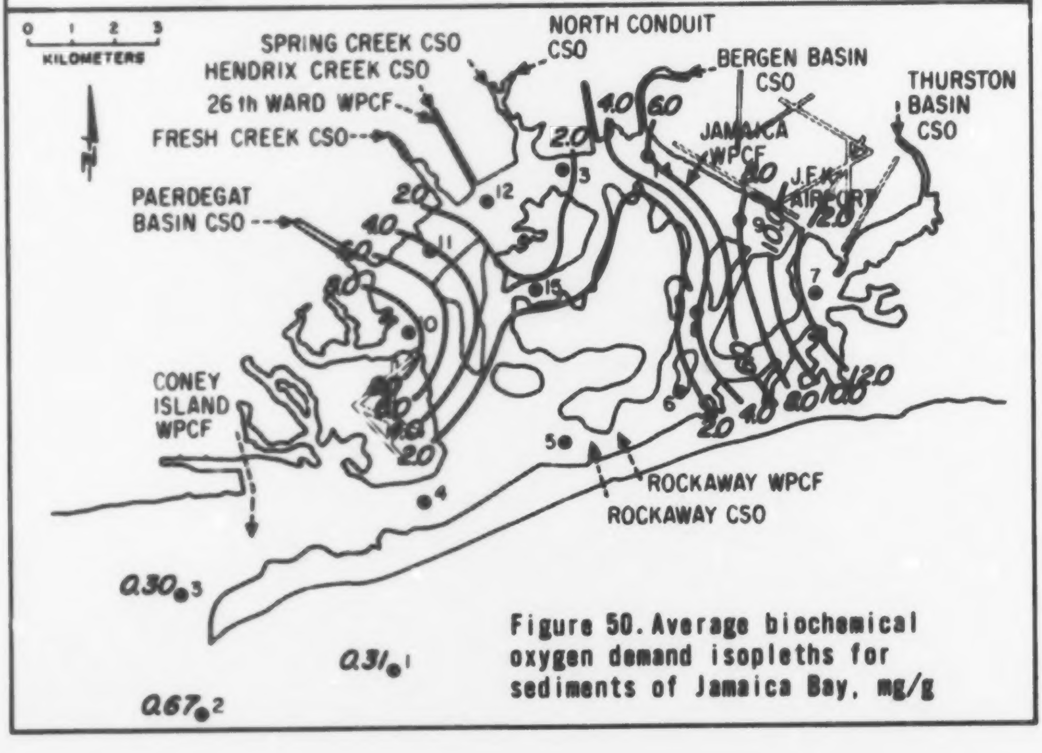
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
THURSTON BASIN CSO
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
2.0
4.0
6.0
8.0
10.0
12.0
2.0
4.0
6.0
8.0
10.0
12.0
0.30 3
0.31 1
0.67 2
4
5
6
7
9
10
11
12
3
15

Figure 50. Average biochemical oxygen demand isopleths for sediments of Jamaica Bay, mg/g

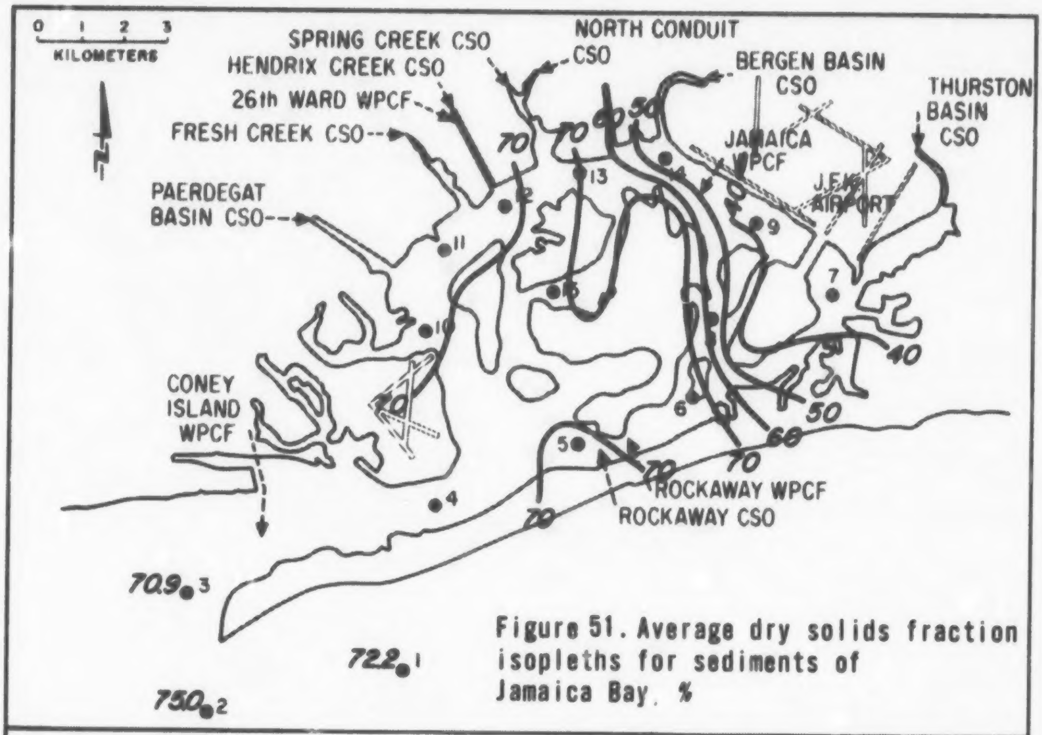
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
70
60
50
40
70.9 3
72.2 1
75.0 2

Figure 51. Average dry solids fraction isopleths for sediments of Jamaica Bay, %

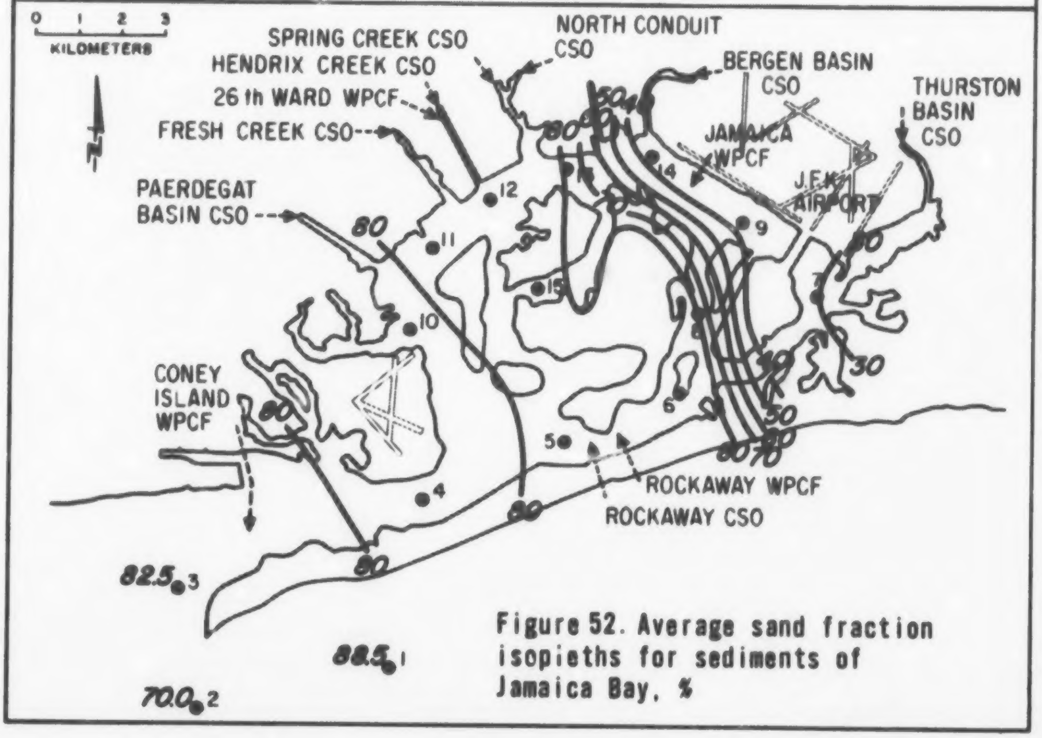
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
80
50
40
30
70
82.5 3
88.5 1
70.0 2

Figure 52. Average sand fraction isopleths for sediments of Jamaica Bay, %

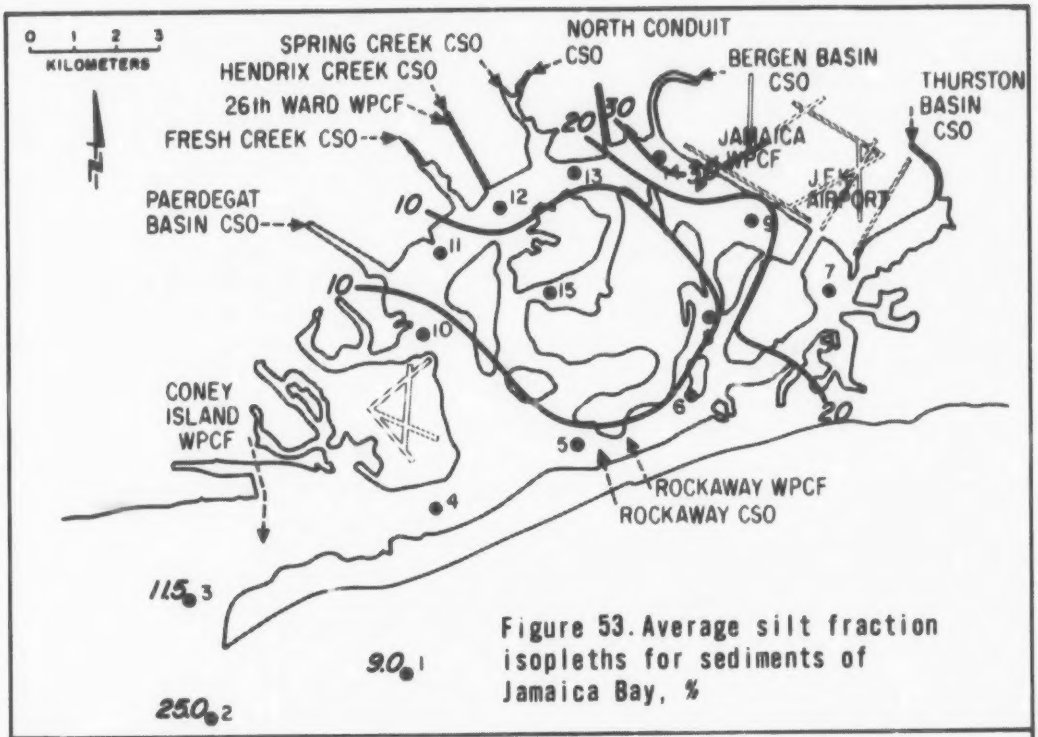
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
10
10
20
30
30
20
13
12
11
15
10
9
7
6
5
4
11.5 3
9.0 1
25.0 2

Figure 53. Average silt fraction isopleths for sediments of Jamaica Bay, %

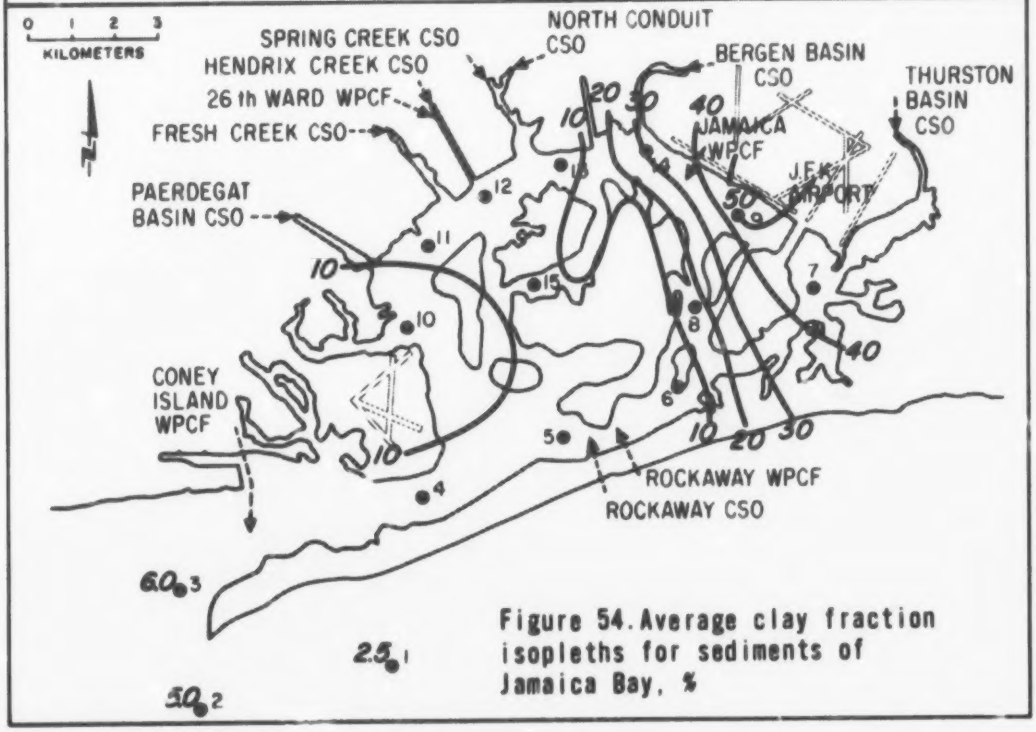
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
NORTH CONDUIT CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
10
20
30
40
50
40
10
10
10
20
30
13
12
11
15
10
8
7
6
5
4
6.0 3
2.5 1
5.0 2

Figure 54. Average clay fraction isopleths for sediments of Jamaica Bay, %

Kjeldahl Nitrogen--

Average Kjeldahl nitrogen content of sediments in Jamaica Bay, shown in Figure 55, ranges from less than 0.5 mg/g in Rockaway Inlet to a maximum of 4 mg/g in Head of Bay. Only slightly elevated average concentrations, somewhat greater than 0.5 mg/g, were observed in the north channel in the vicinity of the 26th Ward sewage treatment facility.

Hexane Extractable Material--

Average benthic concentrations of HEM in Jamaica Bay ranged from less than 0.1 mg/g in Rockaway Inlet to a maximum of greater than 3 mg/g in Grassy Bay near the Bergen Basin combined sewer overflow and the Jamaica sewage treatment facility. These isopleths are shown in Figure 56.

Sulfide--

The spatial distribution of total sulfides in the sediments of Jamaica Bay is shown in Figure 57. Like most of the other sediment quality (pollutant) parameters, the highest average values (greater than 16 mg/g) were observed in Grassy Bay near the Bergen Basin combined sewer overflow. Sulfide concentrations decreased markedly and rather uniformly from Grassy Bay to Rockaway Inlet, where the average concentrations were about 0.1 mg/g.

Total Phosphorus--

Average total phosphorus concentrations in the sediments of Jamaica Bay, shown in Figure 58, increased from values less than 0.2 mg/g in Rockaway Inlet to maxima of greater than 0.7 mg/g in Grassy Bay near the Bergen Basin combined sewer overflow and 1.3 mg/g in Head of Bay.

Benthos--

The average benthic biomass in Jamaica Bay, shown in Figure 59, increased from 2,000 organisms per square meter (org/m^2) in Rockaway Inlet and Head of Bay to more than 10,000 org/m^2 in the immediate vicinity of the 26th Ward sewage treatment facility discharge to the north channel of the bay.

Benthic Diversity Index--

As shown in Figure 60, the maximum average benthic diversity index, of greater than 1.4, was observed in the north channel near the proximity of the 26th Ward sewage treatment facility discharge and corresponded with the maximum observed benthic biomass. Minimal average values of less than 0.2, indicative of more polluted environments, were observed in Grassy Bay.

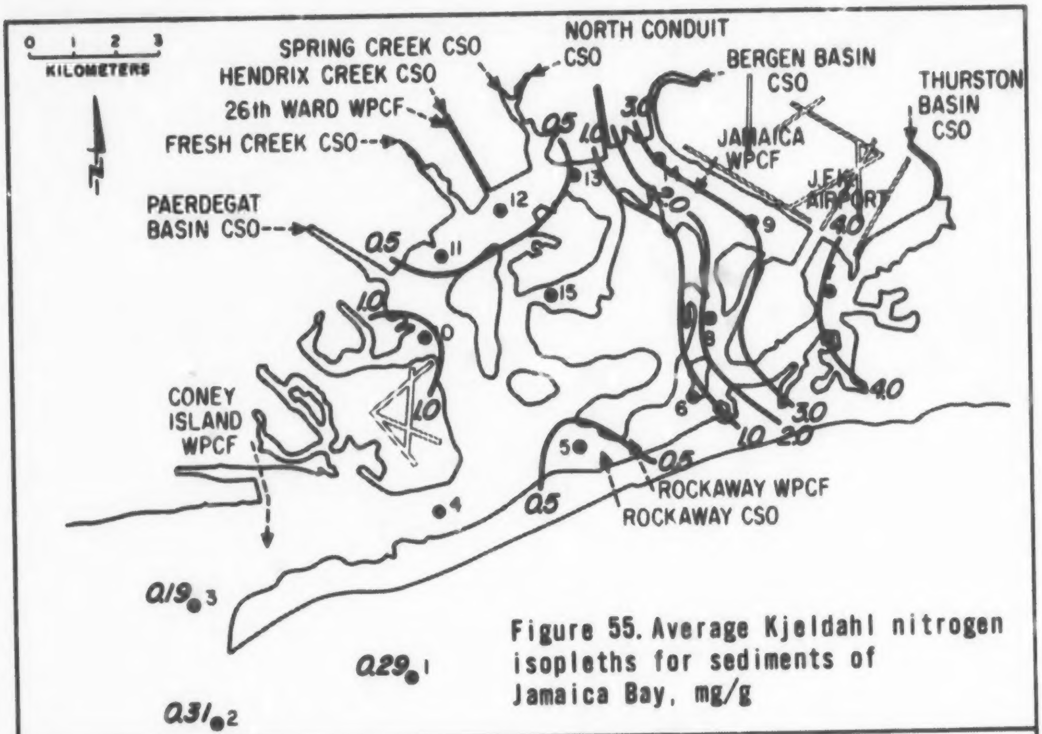
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.5
1.0
3.0
2.0
4.0
0.19 3
0.29 1
0.31 2

Figure 55. Average Kjeldahl nitrogen isopleths for sediments of Jamaica Bay, mg/g

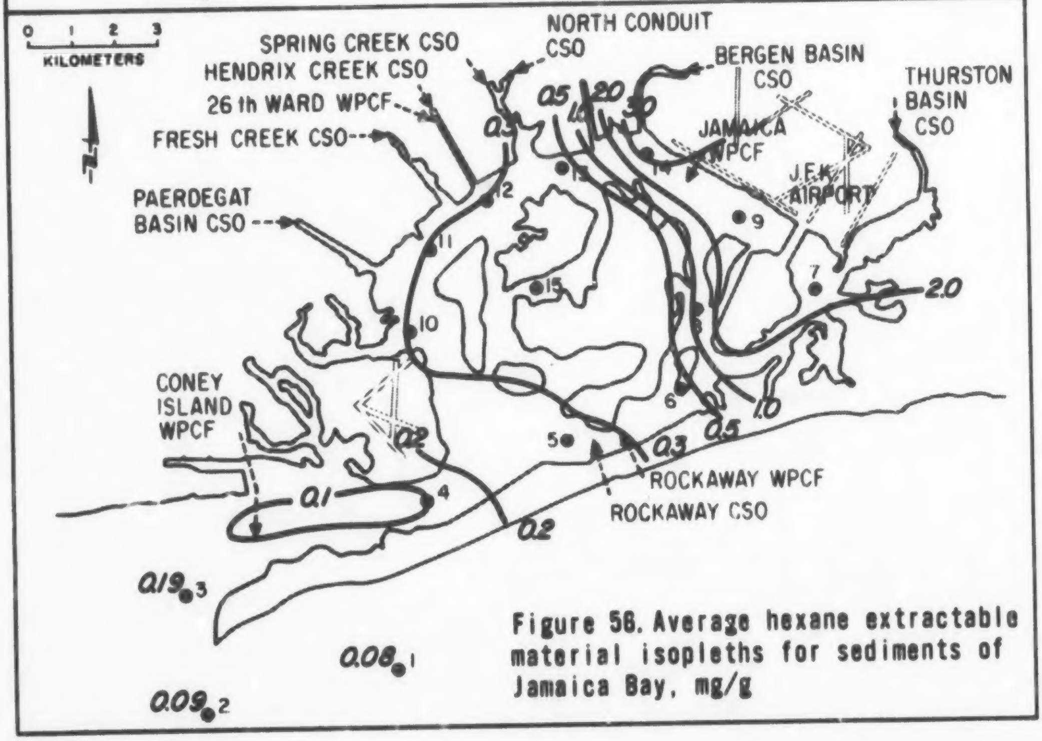
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
THURSTON BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.5
1.0
2.0
3.0
0.3
0.2
0.1
0.19 3
0.08 1
0.09 2

Figure 56. Average hexane extractable material isopleths for sediments of Jamaica Bay, mg/g

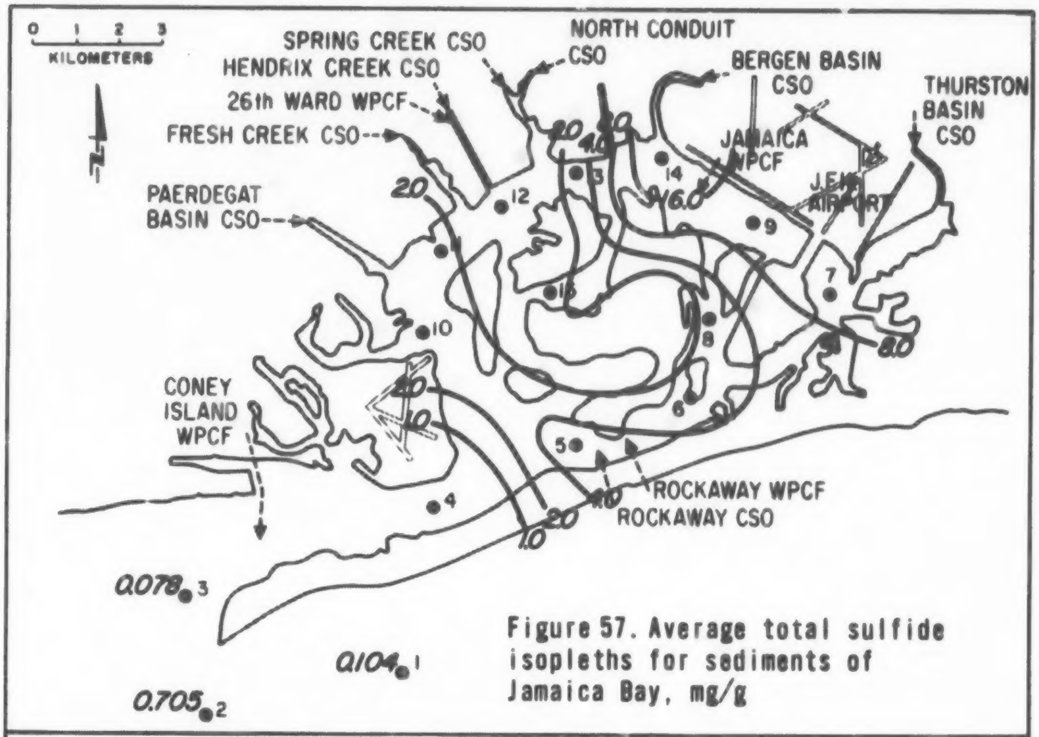
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
2.0
4.0
6.0
8.0
1.0
2.0
4.0
1.0
2.0
12
13
14
9
7
8
6
5
4
10
11
15
0.078 3
0.104 1
0.705 2

Figure 57. Average total sulfide isopleths for sediments of Jamaica Bay, mg/g

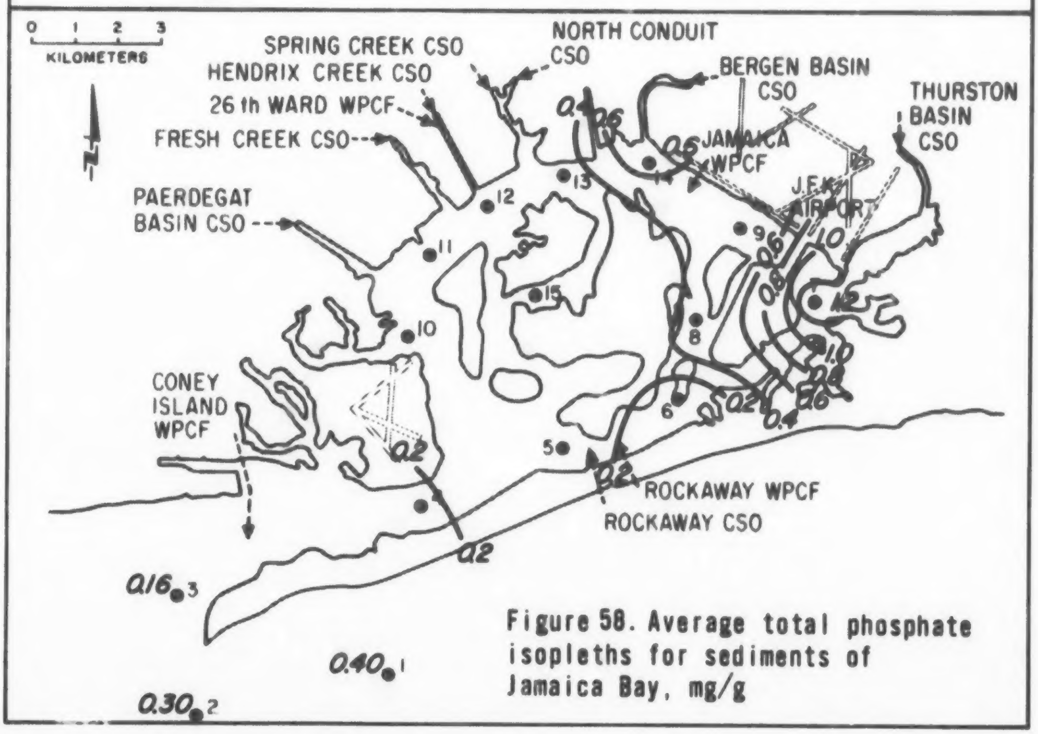
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
0.4
0.6
0.6
0.6
0.8
1.0
1.2
1.0
0.8
0.6
0.4
0.2
0.2
0.2
0.2
12
13
14
9
8
6
5
10
11
15
0.16 3
0.40 1
0.30 2

Figure 58. Average total phosphate isopleths for sediments of Jamaica Bay, mg/g

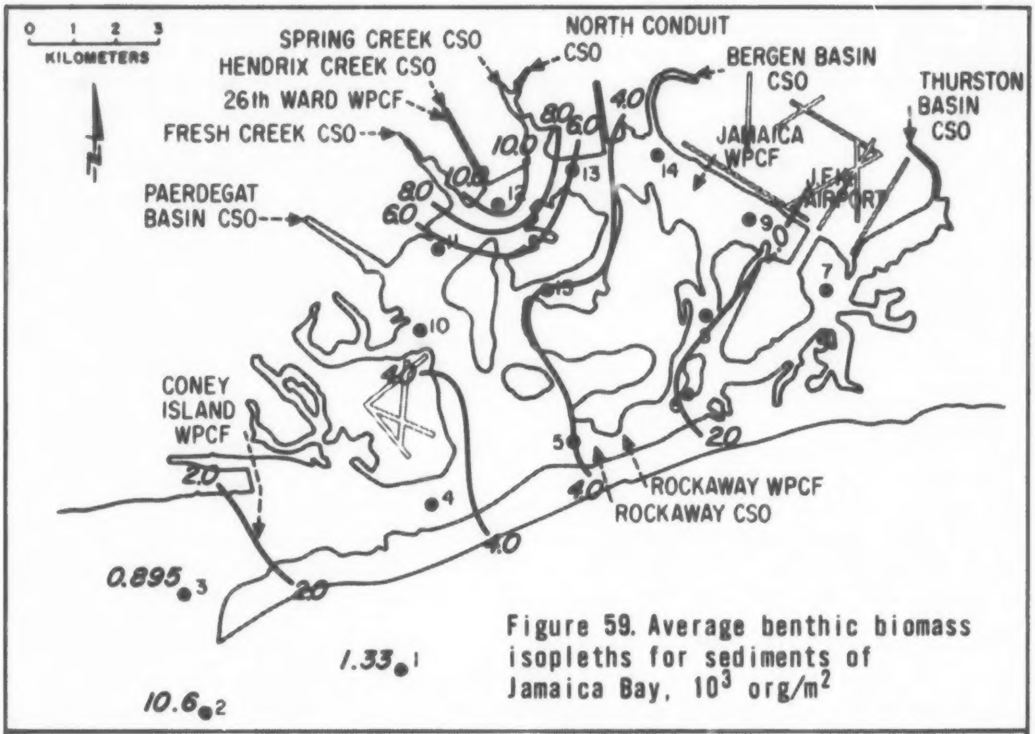
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
10.0
10.0
8.0
6.0
4.0
8.0
6.0
4.0
2.0
2.0
4.0
4.0
2.0
2.0
12
13
14
11
9
7
10
8
6
5
4
0.895 3
1.33 1
10.6 2

Figure 59. Average benthic biomass isopleths for sediments of Jamaica Bay, 10^3 org/m^2

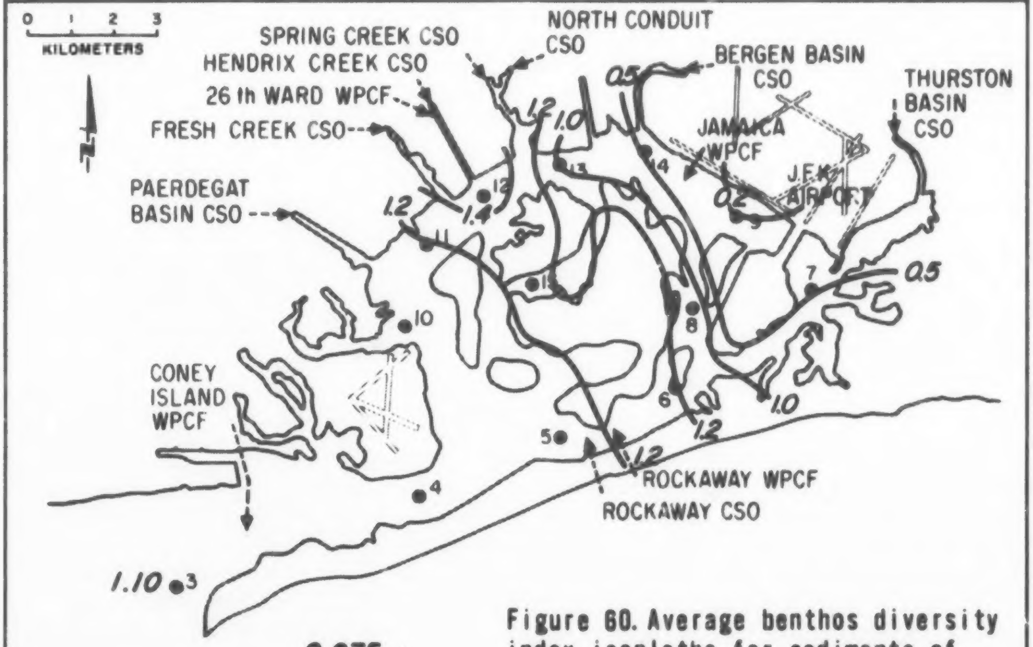
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
26th WARD WPCF
FRESH CREEK CSO
PAERDEGAT BASIN CSO
NORTH CONDUIT CSO
BERGEN BASIN CSO
THURSTON BASIN CSO
JAMAICA WPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY CSO
1.2
1.0
0.5
1.2
1.4
0.2
0.5
1.0
1.2
1.2
12
13
14
11
10
8
7
6
5
4
1.10 3
0.975 1
0.764 2

Figure 60. Average benthos diversity index isopleths for sediments of Jamaica Bay

Special Studies

A number of special studies were conducted during the project to provide a fuller definition of the character of the Jamaica Bay ecosystem. These included an abbreviated water quality and terrestrial ecology characterization of other Long Island bays, fish trawls in Jamaica Bay and other Long Island bays and studies of heavy metal and pesticide content in the wastewater discharges to, and sediments of, Jamaica Bay.

Long Island Bay Sampling--

To provide an assessment of the changes which have occurred in the water quality and biota of Jamaica Bay, a cursory examination of the water quality, marshes and biota of several of the south shore bays was performed. Six stations in the area between Great South Bay and West Hempstead Bay and one station in Jamaica Bay were selected, as shown in Figure 61. Station 15, located in the marsh area of Jamaica Bay, was selected for comparison with the stations sampled in the other bays. Water samples were collected on three occasions over a 7-mo period extending from 30 November 1970 to 3 May 1971 at mid-depth and during low slack water at each of the stations. Sediment samples for analysis were taken at the same stations between 21 December 1970 and 5 May 1971.

Results of these analyses, presented in Table 9, indicate that, with respect to the measured water quality parameters dissolved oxygen, suspended solids, volatile suspended solids, total Kjeldahl nitrogen, ammonia and nitrate, concentrations in Jamaica Bay were not substantially different from those in the other Long Island bays. Biochemical oxygen demand, soluble phosphorus, total coliforms, fecal coliforms, microplankton and zooplankton concentrations were higher on the average in Jamaica Bay than in the other Long Island bays, whereas Secchi disc transparency and chloride concentrations were lower in Jamaica Bay. These water quality data clearly indicate the influence of the wastewater discharges to Jamaica Bay.

Results of the sediment analyses, shown in Table 9, indicate generally lower values for BOD_5, HEM, total Kjeldahl nitrogen, soluble phosphorus and sulfide concentrations at the station in Jamaica Bay in comparison to the other Long Island bays.

Fish Trawls--

A most important group of estuarine organisms, particularly with respect to recreation and commercial activities, comprises the demersal and unattached forms of fish and invertebrates. Many fish and invertebrates are well adapted to withstand the stresses of the estuarine environment and are able to avoid unfavorable effects of wide fluctuations in salinity, dissolved oxygen, temperature and suspended material. For these reasons, and because the estuaries and bays often serve as spawning areas and nurseries for fish, densities and types of fish and in-

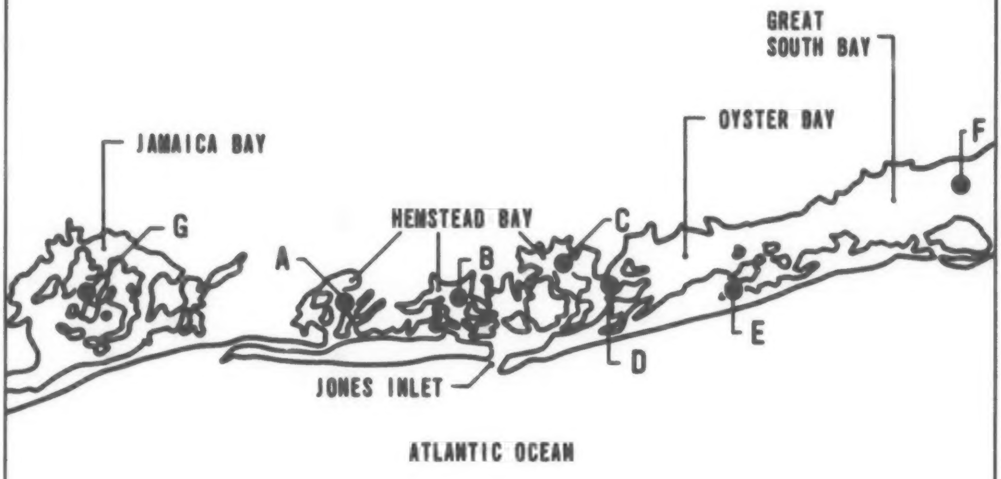
GREAT SOUTH BAY
OYSTER BAY
F
JAMAICA BAY
G
HEMSTEAD BAY
C
A
B
D
E
JONES INLET
ATLANTIC OCEAN

Figure 61. Sampling locations for Long Island bays sampling program

Table 9. WATER QUALITY AND SEDIMENT CHARACTERISTICS OF LONG ISLAND BAYS

Parameter	Sample location						
	Hempstead Bay			Oyster Bay			Jamaica Bay
	West	Middle	East	West	East	South Bay	
	A	B	C	D	E	F	G
Water							
Secchi disc, m	2.2	2.3	1.8	1.7	1.6	1.9	1.4
DO, mg/l	9.9	9.7	9.9	9.9	9.7	10.0	9.9
BOD_5, mg/l	2.1	1.8	2.0	1.9	2.3	3.4	5.7
Suspended solids, mg/l	5.7	5.4	7.2	9.4	9.0	12.3	7.9
Volatile susp. sol., mg/l	1.9	2.3	2.2	2.4	3.5	3.9	3.8
Chloride, g/l	17.1	17.1	17.4	17.8	17.6	16.0	14.2
Kjeldahl nitrogen, mg/l	0.83	1.03	0.58	0.88	0.48	0.48	0.83
NH_3-N, mg/l	0.40	0.38	0.13	0.16	0.13	0.10	0.73
NO_3-N, mg/l	0.32	0.05	0.05	0.03	0.03	0.19	0.15
Soluble phosphorus, mg/l	0.24	0.19	0.07	0.06	0.05	0.03	0.39
Total coliforms, MPN/ml	46.5	21.5	0.60	0.90	0.05	0.22	585
Fecal colfiroms, MPN/ml	1.17	12.0	0.22	0.35	0.05	0.22	141
Microplankton, org/ml	691	893	1,000	841	1,365	789	4,711
Zooplankton, org/ml	17.5	13.0	4.6	9.8	8.7	26.2	128
Sediment							
BOD_5, mg/g	5.52	4.81	5.20	0.54	1.16	4.20	0.55
HEM, mq/g	1.9	1.04	1.5	0.47	0.46	1.6	0.36
Kjeldahl nitrogen, mg/g	2.95	2.34	2.58	0.54	0.80	1.99	0.26
Soluble phosphorus, mg/g	0.53	0.61	0.82	0.20	0.20	0.37	0.27
Sulfide, mg/g	2.15	1.74	3.40	0.03	0.05	1.90	0.10

vertebrates in different areas of Jamaica Bay and in other south-shore Long Island bays were determined. Areas sampled in Jamaica Bay were Island Channel, the north channel, Grassy Bay, Broad Channel and Beach Channel. At each transect a 16-ft otter trawl was lowered and pulled for a known distance or period of time at a known rate of speed. Collected specimens were identified and enumerated to provide a species diversity index.

Results of the fish and invertebrate trawls at the various sampling locations in Jamaica Bay and other Long Island bays are presented in Table 10. On the average, fewer fish were collected in Jamaica Bay; but because the number represented a larger number or variety of species, a higher species diversity index of fish was obtained for Jamaica Bay, which is indicative of a better balanced and more favorable fish community. A larger average number of invertebrates was collected in Jamaica Bay as compared to the other Long Island bays, in addition to a greater number of invertebrate species, which again produced a higher and more favorable invertebrate species index in Jamaica Bay than existed in the other Long Island bays sampled.

Heavy Metals--

The presence of heavy metals in receiving environments may constitute a serious form of pollution because the metals are not readily removed by natural processes. They may persist in the environment for many years after the sources of pollution have been removed. This accumulation is enhanced in Jamaica Bay by the salt marsh environment, which collects heavy metals by formation of sulfides and organic complexes, and by concentration in wetland species.

Results of heavy metal analysis of samples collected during the period June to September 1973 by the Department of Water Resources, City of New York [8] from selected stations in Jamaica Bay are presented in Table 11. Each analysis represents a single sample composited from 30 samples taken half near the surface and half near the bottom during a wide range of tidal and climatic conditions.

Although the heavy metals in Jamaica Bay were not present in concentrations sufficient to cause acute toxicity to marine organisms, their presence is still potentially dangerous. The effect of heavy metals on marine life is often synergistic and will vary not only with concentration and species but also with the physical and chemical properties of the water. In addition to synergistic effects of heavy metals, there are chronic effects which may not become manifest for some time.

Pesticides--

Results of analyses for chlorinated hydrocarbons in the waters and sediments of Jamaica Bay are presented in Table 12 and appear to indicate a gradual increase from Rockaway Inlet to the east end of Jamaica Bay.

Table 10. RESULTS OF FISH AND INVERTEBRATE TRAWLS IN JAMAICA BAY AND OTHER LONG ISLAND BAYS

Sampling location	Fish			Invertebrates		
	No. of organisms	No. of species	Diversity index[a]	No. of organisms	No. of species	Diversity index
Jamaica Bay						
Island Channel	68	10	1.73	82	6	1.28
North Channel	255	10	0.99	309	14	1.18
Grassy Bay	32	6	1.32	68	4	0.94
Broad Channel	76	6	1.15	378	14	2.38
Beach Channel	45	14	2.27	167	9	1.81
Average	95	9	1.49	200	9	1.52
Other Long Island bays						
West Hempstead Bay	530	4	0.09	19	3	0.80
Middle Hempstead Bay	408	4	0.10	0	0	0
East Hempstead Bay	46	5	2.24	5	3	0.95
West Oyster Bay	3	3	1.10	28	5	1.50
East Oyster Bay	1,005	5	0.04	20	4	0.97
Great South Bay	235	5	0.53	23	3	0.47
Average	371	4	0.68	16	3	0.78

[a] Diversity index = $-\sum \frac{n}{N} \log_2 \frac{n}{N}$, where n is number of individual species and N is total number of all species.

Table 11. HEAVY METAL CONCENTRATIONS IN JAMAICA BAY, 1973

Location	Heavy metal, mg/l						
	Copper	Chromium	Nickel	Zinc	Cadmium	Lead	Mercury
Coney Island outfall	0.01	0.001	0.010	0.09	0.0008	0.16	0.0004
Rockaway Inlet	0.07	0.0015	0.015	0.15	0.0032	0.21	0.0005
Mill Basin	0.07	0.0015	0.014	0.10	0.0026	0.18	0.0008
Canarsie Pier	0.07	0.001	0.010	0.12	0.0025	0.20	0.0011
Railroad trestle	0.12	0.0035	0.018	0.14	0.0057	0.20	0.0007
Bergen Basin	0.08	<0.0005	0.021	0.14	0.0024	0.25	0.0022
Average	0.10	0.0015	0.015	0.12	0.0029	0.12	0.0029

Analyses indicate that along with the polychlorobiphenyls (PCB), significant amounts of DDT and its derivatives DDE and DDD are found in the waters of Jamaica Bay, principally in the north channel area. Polychlorobiphenyls were also found in sediment samples in addition to the recognized pesticide dieldrin and two unknown chlorinated hydrocarbons.

The significance of these pesticide concentrations is that they are withdrawn from the water and concentrated by phytoplankton or extracted from sediments by detritus-feeding animals and thereby passed up the food chain. Once the pesticides have reached adequate concentrations in the tissues of fish, they may prove to be toxic under stress or to be physiologically damaging to the reproductive process.

Although the concentrations of total chlorinated hydrocarbons in the waters of Jamaica Bay are not alarming, attention must be called to the paucity of knowledge on the significance of biological magnification. Also, the concentrations of chlorinated hydrocarbons in the sediments of Jamaica Bay were hundreds and even thousands of times greater than they were in the waters. At the present time it is not possible to state all the implications of the chlorinated hydrocarbons in Jamaica Bay; however, it does appear that the levels of chlorinated hydrocarbons in the water pose no significant obstacle to primary-contact recreation. The most serious limitation imposed by high concentrations of chlorinated hydrocarbons would apply to secondary contact recreational activities based upon human consumption of fish and shellfish.

Table 12. CHLORINATED HYDROCARBON CONCENTRATIONS IN WATERS AND SEDIMENTS OF JAMAICA BAY (mg/l)

Date	Station	TCH	PCB	DDE	DDT	DDD	Dieldrin	TUCH
Water								
6 Feb 69	4	0.035						
	11	0.085						
	14	0.110						
21 Nov 69	4		0.08[a]	0.01				
	6		0.08[a]	0.2				
	7		0.04[a]	1.0				
	10		0.06[a]	0.02				
	12		0.05[a]	0.05				
	14		0.02[a]	0.04				
	15		0.06[a]	ND[b]				
10 Apr 70	4		ND[c]	ND	ND	ND		
	7		ND[c]	ND	ND	ND		
	10		0.120[c]	0.014	0.045	0.043		
	12		ND[c]	0.040	0.020	0.006		
	14		ND[c]	0.004	0.022	ND		
Sediment								
6 Feb 69	4		67[d]					
	6		67[d]					
	11		445[d]					
	14		1,835[d]					
	15		225[d]					
21 Nov 69	4		67[a]					
	6		9[a]					
	7		580[a]					
	10		29[a]					
	12		26[a]					
	14		510[a]					
	15		39[a]					
10 Apr 70	4		ND[a]				ND	16
	7		670[a]				19	861
	10		25[a]				1	47
	12		ND[a]				ND	42
	14		1,900[a]				65	1,000

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[a] PCB 1254
[b] ND = not detectable
[c] PCB 1248
[d] PCB total

SECTION VI

ECOSYSTEM MANAGEMENT

MANAGEMENT PERSPECTIVES

Ecosystem Interactions

In an ecosystem, a multitude of biological and chemical components and physical parameters interact in a complex manner to produce a behavior characteristic of that particular ecosystem. The behavior is designed to perpetuate the existence of the biological sector of the system regardless of the nature of the chemical components and physical parameters. Ecosystem behavior is characterized in terms of the number of components in the system, the magnitude and concentration of each component. Because the essence of an ecosystem is the capture, storage, conversion, use and release of energy, the inefficiencies of these operations can result in the accumulation of energy in the system. In general, as the rate of accumulation and level of energy increase, the quality of the ecosystem decreases. Ecosystems are dynamic systems in which all the components are interrelated, such that a change in a component or relationship between components has an effect on all the segments of the system, including the ones which initially changed.

Use Perspectives

There are three essentially distinct ecosystem use-perspectives; namely, the preservation use-perspective, the maximum sustained use-perspective and the destructive use-perspective. The preservation perspective assumes that man must be barred from participating in or having an effect on ecosystems. It is assumed also that changes in ecosystems in the absence of man, regardless of the nature of the changes, are acceptable. Under this use-perspective, if the rate of change is such that an ecosystem will exhibit certain characteristics after a century has passed, the change is acceptable; however, if man's activities are such that the rate of change is increased so that the same characteristics will exist after a decade has passed, the change is unacceptable.

The destructive use-perspective assumes that ecosystems and their components are to be used by man in any manner deemed desirable. Fundamentally, this use-perspective recognizes no limitations of resources. Although based on the apparent assumption that ecosystems will exist, unchanged, in perpetuity regardless of use, this perspective can relate only to short-term situations because it results in the consumption and final destruction of the ecosystem or its components. All situations in which resources are used on the basis of desire or need without regard to supply are examples of this perspective. This has been traditionally the most common approach to man's use of ecosystems in the industrialized nations.

The maximum sustained use-perspective lies between the above extremes and is predicated on the assumption that man is a participant in an ecosystem. There is assumed to be a relationship between uses of an ecosystem and its components and the quality of the ecosystem, and the uses of the ecosystem and its components impart changes to the system which must be corrected or compensated for if the use is to be perpetuated. The latter applies not only to use-induced changes but also to nonuse-related changes which interfere with the specific use. This perspective implies that the purpose of the management of the system is to permit the desired uses of the system to continue; that is, to expend resources for adjustment and modification of the ecosystem so that it continues to manifest the desired characteristics. This approach requires identification of the desired characteristics and permits an assessment of the costs associated with achieving them. The management of fish and game on the basis of sustained yields is a facet of the maximum sustained use-perspective.

It is apparent that the preservation and the destructive use-perspective represent diametrically opposed approaches to ecosystem use. The maximum sustained use-perspective is a flexible approach which allows a particular use of an ecosystem or its components to be determined on the basis of an evaluation of the quantifiable and nonquantifiable benefits and costs to be incurred as a result of the use.

MANAGEMENT TECHNIQUES

The tools available for managing an ecosystem are wastewater input control and treatment, flushing and dredging. Additional management tools which are available, such as harvesting algae and aeration, are considered secondary in importance because they merely cure symptoms and their usefulness may be obviated by implementation of the primary management tools.

Wastewater Management

Management of wastewaters is the traditional and most conventional technique of ecosystem management because wastewaters are usually the most important exogenous influence altering the natural progression of events in an ecosystem. In its widest application, wastewater management encompasses source control and all levels of wastewater treatment, transport and manner of discharge in or outside the ecosystem for beneficial uses.

Dredging

Certain wastewater constituents accumulate in the sediments, posing two problems for ecosystem management. First, these accumulated materials may be incompatible with benthic organisms necessary to the food chain; secondly, they can be periodically released back to the overlying water. Accumulations of wastewater materials in the sediments can cause a gradual change from a desirable to an undesirable ecosystem, whereas the sudden release of these materials can cause periodic disruptions in desirable ecosystem characteristics. At present the only apparent positive way to control these undesirable effects is to physically remove them by the use of dredging. Thus, if at any given location it is desired to maintain an ecosystem which has constant characteristics over time, dredging may be a mandatory ecosystem management technique.

Traditionally, dredging, as routinely practiced in many bays, rivers, lakes, estuaries and harbors, has been conducted for the explicit benefits which accrue to navigation and construction activities. However, there has been a recent growing awareness that if aquatic ecosystems are to be maintained and improved then dredging, as it affects ecosystem status, must be developed to the point where it can be included in the tools and procedures used to combat natural and man-induced eutrophication of natural and man-made water bodies.

In summary, dredging can serve to eliminate an existing benthic ecosystem so that a new one can be initiated, remove sediments so as to create a new habitat and reshape the topography so as to create new circulation patterns, bed load improvement and transport characteristics within the ecosystem. Thus, dredging as an ecosystem management tool must be viewed as having two advantages and a disadvantage. The advantages lie in its value in initiation and maintenance, whereas the disadvantage relates to the problem of handling the dredged material so that it does not create more problems after removal than it did in place.

Flushing

Treated wastewaters can be used to maintain general water quality conditions in aquatic systems as a result of flushing action if the wastewater flow rate is relatively large compared to the natural flow. That is, the partial control of the hydraulics of the system can be used to affect the material residence time and, to some extent, the accumulation of organic and inorganic materials in the sediments and waters. There are essentially three dispersion mechanisms--advective transport, dispersion and decay--which can affect the distribution of materials in an aquatic system. The first two mechanisms affect the distribution of conservative substances, such as mercury, while all the mechanisms affect the distribution of nonconservative substances, such as BOD. Consequently, differences in water movement may govern differences in water constituent concentrations in various parts of Jamaica Bay.

In general, flushing by currents is much more of a controlling and limiting factor in streams than it is in bays. Streams are unique in that they are subject to spring freshets and summer flash floods which essentially reestablish the resident ecosystem conditions at least once each season. However, wave action along shores may virtually duplicate stream conditions.

MANAGEMENT PARAMETERS

One of the more controversial aspects of ecosystem management is the assignment of quantitative values to qualitative benefits arising from use of the various management techniques. Such assignment is desirable, however, because the different management alternatives require comparison with the resulting qualitative benefits. The main difficulty is in the very diverse nature of the many parameters determing degree of accomplishment of the different uses to be sustained by the ecosystem.

Sustained uses to be protected and enhanced through management of the ecosystem are full-contact water sports such as swimming, limited-contact water sports such as fishing, aesthetic enjoyment, fish and wildlife sanctuary, commercial navigation and wastewater transport and disposal.

Broad measures of suitability for these objectives are public health protection, recreational suitability, aesthetic quality, primary productivity and manageability. Manageability is a measure of the ability of the management system to maintain the ecosystem for other beneficial uses. It is evident that a multiple-objective approach can be used if numerical indices, or scalar measures, associated with each of the above areas--as determined by the physical, chemical and biological character of the Jamaica Bay ecosystem--can be developed for each alternative wastewater management system.

Six indices of ecosystem character were formulated:

1. Zero-Risk Index--a measure of public health protection,

2. Water Contact Recreation Index--a measure of availability of the ecosystem for zero-risk water contact,

3. Ecosystem Aesthetic Acceptability--a measure of overall aesthetic impact of ecosystem productivity potential (defined below),

4. Ecosystem Productivity Potential--a measure of the unconstrained level of primary productivity,

5. Ecosystem Zero-Benefit Management Index--a measure of the difficulty of bringing the ecosystem from a given state to a point where management control of productivity can be exerted, and

6. Ecosystem Benefit Management Index--a measure of difficulty of bringing the ecosystem from a point of management control to a given desired level of productivity.

Each of the above indices, in turn, can be described in terms of chemical, physical and biological parameters. These descriptions can then be translated, in accordance with arbitrarily selected procedures, into scalar index values associated with desirable or undesirable characteristics. Such procedures would involve references to standard ecosystems demonstrating the extreme desirable or undesirable characteristics. Because each index is based upon quantifiable--and controllable--ecosystem properties, these indices can be used to identify overall comparative values associated with given management programs.

Zero-Risk Index

The zero-risk index is a measure of the degree to which the public health standard is attained. It is derived from the total coliform concentrations in the water column. Present standards are set such that densities less than 24 MPN/ml represent zero-risk achievement, whereas greater coliform densities are unacceptable. Accordingly, zero-risk index is defined as a step function, with a maximal index value for densities less than or equal to 24 MPN/ml and a minimal value for any densities greater than 24 MPN/ml.

Water Contact Recreation Index

The zero-risk index alone is not adequate for determining the suitability of an ecosystem for water contact recreation because it is a parameter specific for a given situation and time. Assuming that a valid management technique for an ecosystem is the restriction of public access to that system when it is unsuitable for a given use, then the relative amount of time that the ecosystem is available for that purpose becomes a meaningful measure. Enforced restriction of access can be and has been used in Jamaica Bay. Water contact recreation is thus quantified as the percentage of days on which the zero-risk criterion is met and the beaches are open. The distribution of expected coliform levels from the different wastewater management alternatives can be converted into user-days by counting those days on which the 24 MPN/ml standard is not exceeded.

Aesthetic Acceptability Index

Ecosystem aesthetic acceptability is a composite measure of suitability of an ecosystem for recreation or aesthetic use. Pertinent parameters will vary for each aquatic ecosystem and the nature of the desired human interaction with the ecosystem. Parameters can include color, odor, turbidity, floatables and some measure of standing floral and faunal crop. The degree of desirability of an ecosystem, from the aesthetic point of view, is thus highly dependent upon the specific set of uses which are to be sustained therein.

Productivity Potential Index

Ecosystem productivity potential is a measure of the potential of an aquatic ecosystem to support the growth of algae and other consumers. This index is not a measure of the standing crop but of the rate of change of the standing crop in response to limiting light and nutrient conditions. Productivity determines the maximum sustained use which can be obtained from the ecosystem; therefore, control of primary productivity is a basic management objective. Because a major portion of the energy flow in the aquatic ecosystem occurs through the phytoplankton (algae, diatoms, etc.), control of primary productivity is achieved largely through control of phytoplankton. Furthermore, primary productivity rates are sequentially and singularly controlled at any time by the environmental parameter which supports the minimal growth rate. As the magnitude of a potentially controlling parameter shifts, control may well shift from one parameter to another.

The sequential, single-parameter control of growth rate of the primary producers provides a basis for developing a scalar system for defining primary productivity potential. The growth rate of primary producers increases as a function of increasing growth-stimulating parameter level or decreasing growth-retarding parameter level. For Jamaica Bay, three potentially controlling parameters are nitrogen, phosphorus and light. While these may not be the only control parameters, controlling them evidently leads to controlling primary productivity. Furthermore, benthic diversity index is an indicator of stability and health of an ecosystem. Hence, a suitable composite index of ecosystem productivity potential could be obtained by adding the scalar value associated with the minimal--controlling--growth control parameter to the scalar value associated with benthic diversity index.

Zero-Benefit and Benefit Management Indices

The concept of a management index is derived from the stability of productivity in a given control approach, under the potential threat of loss of control of the one rate-limiting parameter. For example, a radiant energy control (high turbidity) may exist along with the abundance of nitrogen and phosphorus. Loss of control through decrease in turbidity or color in the system can cause runaway growth, resulting in a severe management problem.

The characteristic saturation behavior of growth rate curves makes it particularly important to examine two separate components of the management index: the "zero-benefit" index and the "benefit" index. In the zero-benefit range, constituent concentrations or values are above saturation, while in benefit stress, constituent values are below saturation. Reduction of constituent levels through management control of parameters which are in the saturation range results in no observable benefits, in terms of stability or control. An index for each management component can be defined in terms of constituent concentrations.

QUANTIFICATION SYSTEM

Numerical values were derived and assigned to the management parameters or indices and evaluated for the wastewater management alternatives presented in Section VIII. For the conditions extant in the Jamaica Bay ecosystem and the assigned scalar values, the quantification system proved to be too insensitive, providing only small numerical differences between wastewater management alternatives. Thus, widely different ecosystem management techniques produced rather similar numerical values for each index, minimizing the utility of this evaluative tool for wastewater management programs relevant to Jamaica Bay.

The potential merit of the ecosystem management quantification system developed in this project for Jamaica Bay should not be overlooked for applications elsewhere. In those cases where the conditions of the ecosystem are such as to provide a greater response to differences between wastewater management alternatives than was evidenced for Jamaica Bay, the ecosystem management evaluation procedure developed in this project could provide a significant adjunct to more conventional evaluative tools.

SECTION VII

WASTEWATER CHARACTERISTICS AND FACILITIES

WASTEWATER SOURCES

At the present time, wastewaters and surface runoff are discharged at numerous points along the periphery of Jamaica Bay. Treated municipal wastewater effluents are discharged continuously from four major water pollution control facilities operated by the City of New York, from two small military installations and from two minor water pollution control facilities operated by Nassau County. Combined sewer overflows discharge during excessive storm conditions at eight locations, and direct stormwater runoff occurs at many points during wet-weather conditions. Other minor pollutant sources include leachate drainage from two active solid waste disposal sites and surface drainage from the John F. Kennedy International Airport.

Dry-Weather Flow

A population of 1,632,500 persons residing within New York City in the area tributary to Jamaica Bay produces an average dry-weather flow of 249 mgd of sanitary sewage. This total flow is separated into four major sewerage service areas, shown in Figure 2, which each terminate at a major water pollution control facility. In 1972, the four sewerage service areas and their respective annual average daily dry-weather flows were Coney Island, 99 mgd; 26th Ward, 66 mgd; Jamaica, 93 mgd; and Rockaway, 19 mgd.

Combined Sewer Overflow

There are nine distinct drainage basins which culminate in combined sewer systems tributary to the four major water pollution control facilities operated by the City of New York. The total area served by combined sewer systems exceeds 18,900 ac. The areas and other characteristics of the individual combined sewer basins are presented in Table 13. The locations of the individual drainage areas are shown in Figure 62.

Separate Storm Sewer Runoff

A total area of greater than 18,000 ac in the Jamaica Bay drainage basin is served by separate storm sewers. Most of the separate storm sewered areas are located at the northeastern and eastern edges of Jamaica Bay inland of the John F. Kennedy International Airport. Smaller storm drainage areas are located along the northern perimeter of the bay and Rockaway Inlet. The predominate land use in these separately sewered areas is single-family dwellings.

Table 13. COMBINED AND STORM SEWER CHARACTERISTICS OF JAMAICA BAY DRAINAGE BASIN[a]

Drainage basin	Area, ac	WPCF tributary	Estimated overflow coefficient[b]	Predominant land use
Combined sewers				
Spring Creek West[c]	1,874	26th Ward	0.40	Multi-family dwellings, limited open space
Spring Creek East[c]	1,382	Jamaica	0.50	Single-family housing units
Thurston[d]	2,190	Jamaica	0.25	75% single-family, 25% cemetery
Hendrix	492	26th Ward	0.60	Highest population density, multi-family dwellings, commercial
Paerdegat	5,730	Coney Is.	0.40	65% multi-family dwellings, 30% commercial, 5% public buildings
Fresh Creek	2,001	26th Ward	0.40	Multi-family dwellings, commercial
Bergen	2,699	Jamaica	0.50	Single-family dwellings
Rockaway	1,250	Rockaway	0.40	70% multi- and single-family dwellings, 30%
Sheepshead Bay	291	Coney Is.	--	--
Subtotal	18,909			
Separate storm sewers				
Thurston & Bergen	18,083[e]	--	--	Single-family dwellings
Total	36,992			

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[a] Includes portions of the drainage basin within the city limits.

[b] Runoff coefficient is estimated at 0.65 for all basins.

[c] The overflow structures for the sewerage systems serving both Spring Creek basins lead to the Spring Creek facility.

[d] Stormwater from other areas is mixed with combined sewer overflows.

[e] Excludes J.F.K. International Airport, with an area of 4,900 ac.

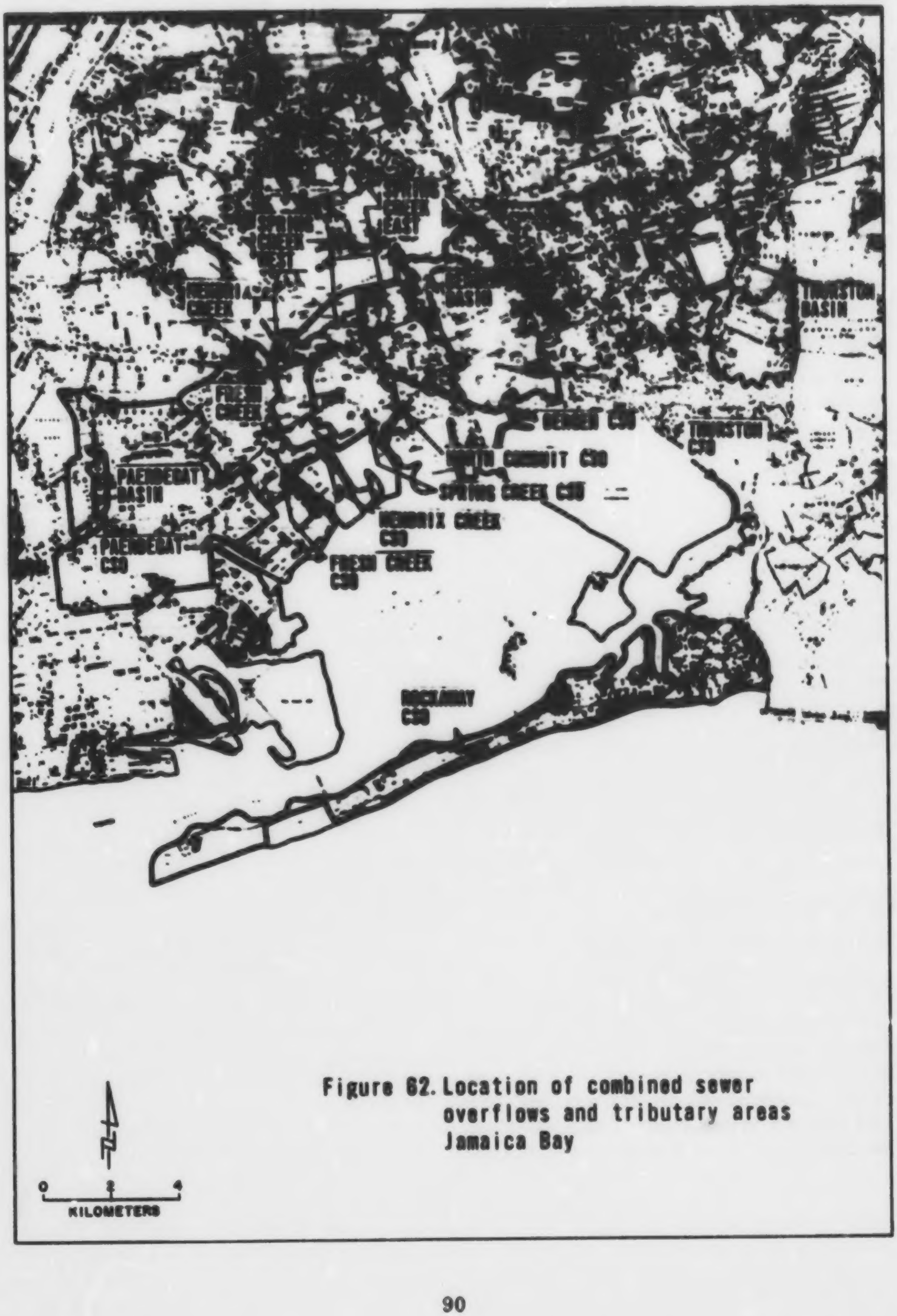
SPRING CREEK EAST
SPRING CREEK WEST
HENDRIX CREEK
BASIN
THURSTON BASIN
FRESH CREEK
BERGEN CSO
THURSTON CSO
NORTH CONDUIT CSO
SPRING CREEK CSO
PAERDEGAT BASIN
HENDRIX CREEK CSO
PAERDEGAT CSO
FRESH CREEK CSO
ROCKAWAY CSO
0
2
4
KILOMETERS

Figure 62. Location of combined sewer overflows and tributary areas Jamaica Bay

Other Sources of Wastewater

The two active landfill sites contributing leachate flows to the bay are the Hendrix landfill and the Rockaway landfill. These two landfills are owned and operated by New York City for disposal of municipal solid waste. Commercial and private dumping is limited. All types of refuse, except flammables, are placed at these sites. The Hendrix landfill site is 370 ac in area and the Rockaway site is 120 ac in area. The Hendrix site has 4,000 ft of frontage on Spring Creek, Hendrix Creek and North Channel. Rockaway landfill has 4,000 ft of frontage on Norton Basin and Grass Hassock Channel.

Another source of wastewaters is the John F. Kennedy International Airport, which occupies 4,900 ac on the northeast perimeter of Jamaica Bay. One half of the stormwater runoff is discharged to Grassy Bay, 25% flows into Bergen Basin and another 25% culminates in Thurston Basin. Sanitary wastewater is discharged separately to the Jamaica sewage treatment facility.

WASTEWATER TREATMENT FACILITIES

Four major water pollution control facilities for treatment of dry-weather flows (Coney Island, Rockaway, 26th Ward and Jamaica) and an auxiliary water pollution control facility for treatment of combined sewer overflow (Spring Creek) comprise the existing wastewater quality management facilities of the City of New York for Jamaica Bay. The process performance of three of the dry-weather flow facilities is being upgraded (upgrading of the fourth is planned) and the auxiliary facility has been constructed in response, in part, to the early findings of this study.

Coney Island Water Pollution Control Facility

The Coney Island facility serves a population of 617,000. It is a modified aeration plant with a discharge of about 99 mgd. Chlorination is practiced only during the summer recreational season, from May 15 to September 30. Chlorine contact occurs in the outfall, which provides approximately 0.5 hr detention time after chlorine is applied. The tributary area is comprised of Paerdegat Basin and Sheepshead Bay Basin.

Rockaway Water Pollution Control Facility

The Rockaway facility service area has a population of 80,500. Prior to upgrading to step aeration, it was a modified aeration plant with a discharge of approximately 19 mgd. Chlorination is accomplished using a conventional contact chamber. The Rockaway Peninsula area sewers are tributary to the plant.

26th Ward Water Pollution Control Facility

The 26th Ward facility serves 370,000 persons. Prior to upgrading to step aeration, the facility was a modified aeration plant with a discharge of 66 mgd. Chlorine is added at the terminal end of the final settling tank and the flow is immediately discharged. Fresh Creek, Hendrix Creek and Spring Creek West basins are tributary areas of this plant.

Jamaica Water Pollution Control Facility

The Jamaica facility serves 565,000 persons. Prior to upgrading to step aeration, it was a modified aeration plant with a discharge of 93 mgd. It has a chlorination system similar to that utilized at Coney Island. This plant receives wastewater from the Spring Creek West, Bergen and Thurston basins.

Spring Creek Auxiliary Water Pollution Control Facility

In conjunction with the upgraded dry-weather flow facilities, the City of New York has planned a program for construction of auxiliary facilities to control the adverse effects of overflows from combined sewers to Jamaica Bay.

An initial step in this program was the design and construction of the Spring Creek Auxiliary Water Pollution Control Facility. This facility is one of the largest installations in the country for management of combined sewer overflows. The facility was partially operational at the onset of the 1972 summer recreational season and is now complete.

The facility is located at the head of Spring Creek and receives combined sewage overflows from Spring Creek East and Spring Creek West basins, as shown on Figure 62. The total tributary area in the two outlets covers approximately 3,260 ac. The facility is designed as a retention basin providing for chlorination of overflows and removal of settleable and floatable solids. After cessation of overflow, the wastewaters are routed, through an interceptor, to the 26th Ward sewage treatment facility for treatment.

Major components and characteristics of the Spring Creek facility are a disinfection system with four hypochlorinators; six retention basins with a surface area of 142,800 ft^2 and a capacity of 1,657,000 ft^3 designed for a hydraulic loading of 2,900 mgd, equivalent to a 5-yr storm; and complete dewatering system and basin cleaning facilities.

During periods of overflow, combined sewer overflows are diverted through the chlorine diffusion chambers and into the inlet chamber for distribution to the retention basins. The overflow volumes that cannot be retained in the basins are discharged to Spring Creek and thence to Jamaica Bay.

After cessation of overflow, the basins are emptied by gravity to the level of the diversion weir in the combined sewer from the Spring Creek West Basin, which is 63% of the full basin volume. The remaining volume in the basins is pumped out to the 26th Ward facility.

In the ensuing cleaning process, traveling spray bridges move from downstream to upstream in each basin and flush grit and sludge along the back-sloped bottoms of the basins to collector troughs leading to the basin drain system. The flushings from the dewatered basin are screened and degritted, and the facility is then readied for the next overflow treatment operation. Basic design criteria are presented in Appendix A.

WASTEWATER QUALITY

Untreated Sewage

The average quality of untreated, dry-weather sewage flowing from the service areas into each of the four water pollution control facilities is presented in Table 14 in terms of concentrations and mass emission coefficients of the various water quality parameters. The parameters reported are: 5-day, 20°C biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), suspended solids (SS), hexane extractable materials (HEM), total nitrogen (TN), total inorganic nitrogen (TIN), total organic nitrogen (TON), total phosphorus (TP) and total soluble phosphorus (TSP). Relevant data on flows and populations served by each plant are also included for ready reference.

Water Pollution Control Facilities Effluent

Average effluent characteristics of the four water pollution control facilities prior to their upgrading and the corresponding waste loadings in million pounds per year (mil lb/yr) to Jamaica Bay are presented in Table 15. These effluent qualities which are related to average constituent removal efficiencies for the four facilities prior to upgrading are presented in Table 16, together with estimated removal efficiencies following upgrading.

After upgrading, it is estimated that the much improved quality of the effluent will have the average characteristics shown in Table 17, which also presents the corresponding average wastewater constituent loadings to Jamaica Bay.

Combined Sewer Overflows

Because of the dilution effect of the storm waters upon sewage and the time-variant nature of stormwater quality itself, combined sewer overflows exhibit quality characteristics which are functions of time and of intensity and duration of rainfall. A number of empirical relationships have been tested to describe overflow parameter concentration as a function of storm intensity. These relationships were tested using

Table 14. AVERAGE UNTREATED DRY-WEATHER WASTEWATER QUALITY, MASS EMISSION COEFFICIENTS AND FLOWS INFLUENT TO WATER POLLUTION CONTROL FACILITIES, 1970[a]

Parameter	Coney Island		Rockaway		26th Ward		Jamaica	
	mg/l	pcd[b]	mg/l	pcd	mg/l	pcd	mg/l	pcd
BOD_5	133	0.160	88	0.171	97	0.142	129	0.171
COD	377	0.454	337	0.656	283	0.415	496	0.657
SS	144	0.173	125	0.243	112	0.164	173	0.230
HEM	18	0.022	16	0.032	31	0.045	25	0.033
TN	49	0.059	45	0.088	45	0.066	37	0.049
TIN	21	0.026	20	0.039	21	0.030	10	0.014
TON	28	0.033	25	0.050	24	0.036	27	0.035
TP	8	0.010	9	0.017	6	0.010	11	0.015
TSP	5	0.005	5	0.009	5	0.007	9	0.013
Population	617,000		81,400		375,000		566,000	
Flow, mgd	89		19		66		90	
Flow, gcd[c]	144		233		176		159	

[a] BOD_5 and SS values are annual averages reported by the Bureau of Water Pollution Control for 1970. All other parameter values are averages of results from analysis of samples collected by Engineering-Science, Inc. in November 1969 and February 1970.

[b] pcd = pounds per capita per day.

[c] gcd = gallons per capita per day.

Table 15. AVERAGE WATER POLLUTION CONTROL FACILITY EFFLUENT CHARACTERISTICS AND LOADINGS TO JAMAICA BAY PRIOR TO UPGRADING OF FACILITIES, 1970

	Coney Island		Rockaway		26th Ward		Jamaica		Total
Parameter	mg/l	mil lb/yr	mg/l	mil lb/yr	mg/l	mil lb/yr	mg/l	mil lb/yr	mil lb/yr
BOD_5	55	14.8	35	2.03	36	7.19	58	15.9	39.9
COD	117	31.7	81	4.68	130	26.1	124	33.9	96.4
SS	45	12.1	60	3.47	46	9.20	79	21.9	46.7
HEM	5	1.49	14	0.82	13	2.65	6	1.64	6.60
TN	37	9.97	37	2.17	28	5.51	32	8.71	26.4
TIN	17	4.57	16	1.09	13	3.20	9	2.46	11.3
TON	20	5.80	21	1.14	15	3.77	23	6.15	16.9
TP	5	1.76	6	0.31	5	1.25	10	2.79	6.11
TSP	3	0.65	5	0.24	4	0.82	9	2.61	4.32

Table 16. AVERAGE WASTEWATER CONSTITUENT REMOVALS FOR WATER POLLUTION CONTROL FACILITIES OF JAMAICA BAY PRIOR TO AND AFTER UPGRADING
(%)

Parameter	Prior to upgrading (1970)				All, after upgrading
	Coney Island	Rockaway	26th Ward	Jamaica	
BOD_5	59	60	63	55	85
COD	69	76	54	75	80
SS	69	52	59	54	85
HEM	70	14	57	76	85
TN	25	17	39	14	--
TIN	22[a]	6[a]	22[a]	15[a]	40
TON	--	--	--	--	20
TP	22	39	9	10	25
TSP	42	9	14	3	20

[a] NH_3-N only.

Table 17. AVERAGE UPGRADED WATER POLLUTION CONTROL FACILITY EFFLUENT CHARACTERISTICS AND LOADINGS TO JAMAICA BAY

	Coney Island		Rockaway		26th Ward		Jamaica		Total
Parameter	mg/l	mil lb/yr	mg/l	mil lb/yr	mg/l	mil lb/yr	mg/l	mil lb/yr	mil lb/yr
BOD_5	20	6.01	13	0.910	15	3.01	19	5.55	15.5
COD	75	22.6	67	4.69	57	11.5	100	29.2	68.0
SS	22	6.63	19	1.33	17	3.42	26	7.60	19.0
HEM	3	0.904	2	0.140	5	1.01	4	1.17	3.22
TN	35	10.6	32	2.24	32	6.43	27	7.89	27.2
TIN	13	3.92	12	0.840	12	2.41	6	1.75	8.92
TON	22	6.63	20	1.40	20	4.02	21	6.14	18.2
TP	6	1.81	7	0.490	5	1.01	8	2.34	5.65
TSP	4	1.21	4	0.280	4	0.804	7	2.05	4.34
Design flow, mgd	99		23		66		96		

data collected during a large number of actual storms in the Jamaica Bay area.

A total of 44 overflow events were monitored in 5 of the 9 basins. The basins in which overflows were monitored were Spring Creek East at the North Conduit, Paerdegat, Spring Creek West, Hendrix Creek and Thurston. The overflows were monitored at frequent intervals during each event. Flow rates were measured at each interval and each sample was analyzed for BOD$_5$, COD, SS, HEM, TON, TIN, TSP and indicator organism concentrations. Mass emission coefficients were developed as a basis for estimating combined sewage emissions to Jamaica Bay as a function of overflow quantity on an individual storm basis.

To develop predictive relationships describing cumulative mass emissions as a function of overflow volume, empirical relationships were evaluated between the cumulative mass emission coefficient for each monitored constituent and overflow volume. Cumulative mass emission coefficients were calculated for each constituent from the basic data for the 44 monitored storms, and plotted against storm overflow depth, producing a linear relationship relatively independent of drainage basin. The limited scatter in the data represent the effects of different land use and sewer system capacity in the different basins, the antecedent dry period and other factors. These data are presented in Appendix B. Weighted average mass emission rates, expressed in pounds per acre-inch of overflow (lb/ac-in.), were developed from these data and are presented in Table 18 for each combined sewer overflow basin. Average concentrations of pollutants in untreated combined sewer overflows to Jamaica Bay from each basin are given in Table 19.

Average mass emission rates were applied with the overflow coefficients and areas of the particular basins to develop average total pollutant loadings from the untreated combined sewage overflows. The results are presented in Table 20.

Auxiliary Water Pollution Control Facility Effluents

Total storage volume of the Spring Creek Auxiliary Water Pollution Control Facility below the level of the outflow weirs is 1,657,000 ft^3, which is equivalent to 0.25 in. of rainfall (0.11 in. of overflow volume) if upstream sewer storage capacity is ignored*. For storms gener-

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*Upstream sewer storage capacity was ignored in analysis of all combined sewer overflow basins, producing an overly conservative design. In reality, overflow from the Spring Creek Auxiliary Water Pollution Control Facility occurs only after about 0.50 in. of rainfall has fallen on the tributary area. However, because the capacity and performance characteristics of this facility were extended to all other combined sewer overflow basins, and because the upstream sewer storage capacity in these basins was not known, the more conservative analysis was believed warranted.

Table 18. AVERAGE MASS EMISSION COEFFICIENTS OF UNTREATED COMBINED SEWER OVERFLOWS TO JAMAICA BAY (lb/ac-in. of overflow)

Parameter	Paerdegat Basin	Fresh Creek	Hendrix Creek	Spring Creek West	Spring Creek East	Bergen Basin	Thurston Basin	Rockaway Peninsula	Total
BOD_5	18.0	24.1	28.7	21.5	32.1	24.1	20.1	24.1	193
COD	82.1	82.1	86.9	58.8	96.1	82.1	86.6	82.1	657
SS	18.4	66.1	57.8	77.3	126	66.1	50.5	66.1	529
HEM	4.20	17.0	14.4	50.3	11.4	17.0	4.57	17.0	136
TN	3.60	3.73	3.91	4.66	4.12	3.73	2.38	3.73	29.9
TIN	1.20	0.84	0.77	1.24	0.63	0.84	0.38	0.84	6.74
TON	2.40	2.89	3.14	3.42	3.49	2.89	2.00	2.89	23.1
TP	2.66	0.77	1.19	0.85	1.00	0.77	0.55	0.77	8.56
TSP	0.20	0.58	0.89	0.64	0.75	0.58	0.41	0.58	4.63

Table 19. AVERAGE QUALITY CHARACTERISTICS OF UNTREATED COMBINED SEWER OVERFLOWS TO JAMAICA BAY (mg/l)

Parameter	Paerdegat Basin	Fresh Creek	Hendrix Creek	Spring Creek West	Spring Creek East	Bergen Basin	Thurston Basin	Rockaway Peninsula
BOD_5	130	130	170	101	115	130	134	130
COD	370	370	390	260	448	370	381	370
SS	315	315	329	268	306	315	357	315
HEM	55	55	95	42	57	55	26	55
TN	18	18	20	25	15	18	12	18
TIN	5	5	4	9	4	5	2	5
TON	13	13	16	16	11	13	10	13
TP	5	5	5	7	4	5	3	5
TSP	3	3	3	5	3	3	2	3

Table 20. AVERAGE ANNUAL POLLUTANT LOADINGS TO JAMAICA BAY FROM UNTREATED COMBINED SEWER OVERFLOWS (mil lb/yr)

Parameter	Paerdegat Basin	Fresh Creek	Hendrix Creek	Spring Creek West	Spring Creek East	Bergen Basin	Thurston Basin	Rockaway Peninsula	Total
BOD_5	1.81	0.85	0.37	0.71	0.97	1.43	0.44	0.53	7.11
COD	8.27	2.89	1.13	1.94	2.92	4.87	1.88	1.80	25.7
SS	1.86	2.32	0.75	2.54	3.83	3.92	1.10	1.45	17.8
HEM	0.42	0.60	0.19	1.66	0.35	1.01	0.10	0.37	4.70
TN	0.36	0.13	0.05	0.15	0.13	0.22	0.05	0.08	1.17
TIN	0.12	0.03	0.01	0.04	0.02	0.05	0.01	0.02	0.30
TON	0.24	0.10	0.04	0.11	0.11	0.17	0.04	0.06	0.87
TP	0.27	0.03	0.02	0.03	0.03	0.05	0.01	0.02	0.46
TSP	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.01	0.14

ating less than this amount of overflow, there will be total capture and partial removal of pollutant constituents in this volume by subsequent processing and treatment at the 26th Ward facility. Under these conditions, it is estimated that approximately 85% of the BOD_5, HEM and SS, 80% of the COD, 40% of the TIN, 25% of the TP and 20% of the TSP and TON are removed under average circumstances. For rainfall depths greater than 0.25 in., the system acts as a sedimentation basin operating at increasing surface loading with decreasing performance efficiency.

The assumed performance curves developed for the Spring Creek treatment facility, and presented in Figure 63, were used to estimate effluent quality and loadings from all future auxiliary water pollution control facilities for treatment of combined sewer overflows. These curves are based on general performance characteristics of sedimentation basins operating under conditions similar to those prevailing in the Jamaica Bay area. Removal efficiencies obtained for an "average" 0.5-in. storm overflow volume were applied to average total pollutant loadings to produce estimated wastewater constituent loadings from each basin if an auxiliary facility were constructed with the same performance characteristics as those assumed for the Spring Creek facility. These estimated loadings are presented in Table 21.

For 14 mo from June 1972 through October 1973 (excluding a 3-mo period extending from 1 April to 27 June 1973 when the 26th Ward treatment facility was unable to routinely dewater the Spring Creek facility), there were 136 days when rainfall of 0.01 in. or more occurred and a total of 105 days when at least 0.06 in., termed a storm, fell during the 24-hr period. During these 14 mo, the Spring Creek facility discharged to Jamaica Bay on 26 days, or for 25% of the storms. Average monthly rainfall during this 14-mo period was 4.14 in., which was about 12% above the long-term monthly average of 3.66 in. Of the total amount of stormwater runoff entering the combined sewer system (assuming a runoff coefficient of 0.65 and a tributary area of 3,256 ac) during this period, namely 3,352 mil gal., it was estimated by the Division of Plant Operations, City of New York, that 1,153 mil gal., or 35% of the total, were treated and discharged from the Spring Creek facility to Jamaica Bay. The remainder either flowed directly to the 26th Ward facility or was eventually received there following temporary storage in the Spring Creek facility.

During the period from January through June 1974, it was estimated by the Division of Plant Operations that 828 mil gal. of stormwater runoff entered the sewer system, of which 84 mil gal., or 10% of the total, was treated at the Spring Creek facility and discharged directly to Jamaica Bay. The average monthly rainfall during this 6-mo period was 2.37 in., which is about 35% below the long-term monthly average.

Results composited from seven storms during 1974 that caused discharge from the Spring Creek facility to the bay indicated an average effluent suspended solids concentration of 79 mg/l and an average effluent BOD_5

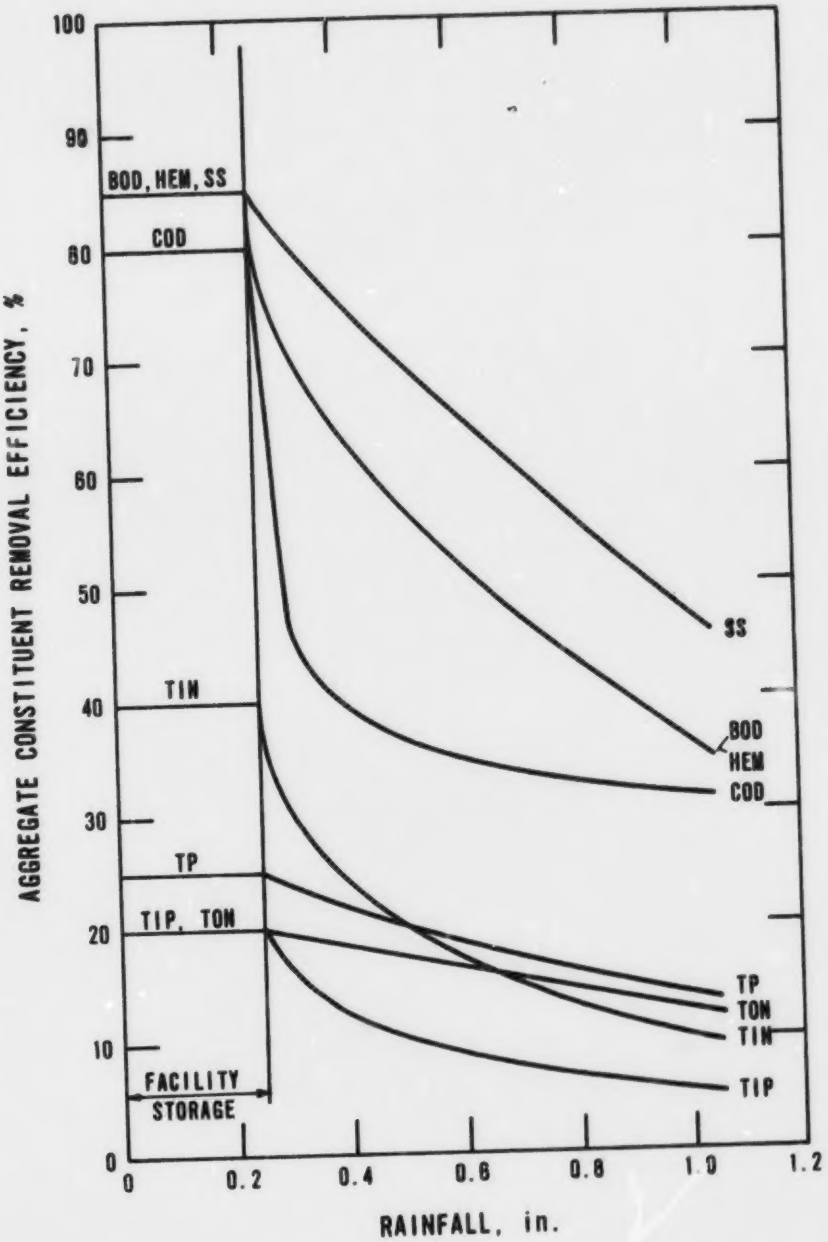

Figure 63. Assumed performance of Spring Creek Auxiliary Water Pollution Control Facility

Table 21. AVERAGE ANNUAL POLLUTANT LOADINGS TO JAMAICA BAY FROM COMBINED SEWER OVERFLOWS PROVIDED WITH AUXILIARY WATER POLLUTION CONTROL FACILITIES
(mil lb/yr)

Parameter	Paerdegat Basin	Fresh Creek	Hendrix Creek	Spring Creek	Bergen Basin	Thurston Basin	Rockaway Peninsula	Total
BOD_5	0.72	0.34	0.15	0.67	0.57	0.18	0.21	2.84
COD	5.38	1.88	0.73	3.16	3.17	1.22	1.17	16.7
SS	0.56	0.70	0.23	1.91	1.18	0.33	0.44	5.33
HEM	0.17	0.24	0.08	0.80	0.40	0.04	0.15	1.88
TN	0.296	0.109	0.011	0.066	0.185	0.042	0.067	0.776
TIN	0.096	0.024	0.008	0.046	0.040	0.008	0.016	0.240
TON	0.200	0.085	0.003	0.018	0.145	0.034	0.051	0.536
TP	0.216	0.024	0.016	0.048	0.040	0.008	0.016	0.368
TSP	0.018	0.018	0.009	0.036	0.027	0.009	0.009	0.126

concentration of 30 mg/l. Average composite removals during these discharge occurrences from the Spring Creek facility were 2.4% for suspended solids and 31.4% for BOD_5. Analyses performed by the Division of Plant Operations during the 14-mo period from June 1972 through October 1973 indicated overall average effluent concentrations of 54 and 29 mg/l for suspended solids and BOD_5, respectively.

Chlorination was initiated at the Spring Creek facility in 1974. Analyses performed by the Division of Plant Operations on four overflowing storms indicated geometric average fecal coliform densities of 6, 3, 1 and 300 org/100 ml. Chlorine (sodium hypochlorite) dosages ranging from 25 to 35 mg/l have resulted in average chlorine residual levels of 2.5 to 3.0 mg/l.

Separate Storm Sewer Runoff

A large area in Jamaica Bay basin is served by separate storm sewers which discharge directly to Jamaica Bay. Along with the runoff waters, a great quantity of litter, domestic animal waste products and other materials are washed into the bay. The weighted average concentrations of the various pollutant constituents were measured for a typical storm and were used as a basis for computing mass emission coefficients of the various pollutants. Both concentrations and mass discharge coefficients are presented in Table 22, wherein computed total loadings are also shown. Total loadings were calculated for an annual average precipitation of 43.93 in. over an area of 18,083 ac.

Other Discharges

Leachate flows from the Hendrix Creek and Rockaway landfills were monitored in the course of the study. Estimates of mass flows of pollutant discharges from the landfill sites were based on infiltration and evaporation assessments. Average flow from the Hendrix site is estimated to be 0.10 mgd and that from the Rockaway site to be 0.05 mgd.

The results of the leachate monitoring program and the estimated flow rates were used to make gross estimates of the annual mass emissions of pollutants from the two sites. These loadings are presented in Table 23.

Total Wastewater Loadings in Jamaica Bay Basin

Wastewater loadings from the various sources contributing to Jamaica Bay are summarized in Tables 24 through 27, presenting loadings of each constituent as a function of the particular stage in the wastewater management program of New York City. It is evident from Tables 24 through 27 that the dry-weather flow treatment facility effluents contribute by far the largest percentage of pollutants, particularly nutrients, to Jamaica Bay. While nutrients contributed by these facilities are generally over 90% of the total nutrient loads under

Table 22. AVERAGE CHARACTERISTICS AND TOTAL POLLUTANT LOADINGS OF SEPARATE STORM SEWER RUNOFF TO JAMAICA BAY

Parameter	Concentration, mg/l	Mass emission coefficient, lb/ac-in.	Total loading, mil lb/yr
BOD$_5$	18.0	4.08	2.1
COD	46.3	10.5	5.3
SS	77.0	17.4	8.8
HEM	2.8	0.63	0.3
TN	1.17	0.26	0.1
TIN	0.55	0.12	0.06
TON	0.62	0.14	0.07
TP	0.31	0.09	0.05
TSP	0.20	0.07	0.04

Table 23. ESTIMATED ANNUAL POLLUTANT LOADINGS FROM LANDFILLS IN THE JAMAICA BAY BASIN (lb/yr)

Parameter	Hendrix Creek site	Rockaway site	Total
BOD$_5$	11,500	9,200	20,700
COD	70,000	55,000	125,000
SS	8,900	6,400	15,300
HEM	1,200	750	1,950
TN	42,100	3,100	45,200
TIN	30,600	1,400	32,000
TON	11,500	1,700	13,200
TP	450	3.1	453
TSP	340	2.3	342

Table 24. AVERAGE ANNUAL WASTEWATER POLLUTANT LOADINGS TO JAMAICA BAY FROM WATER POLLUTION CONTROL FACILITIES PRIOR TO UPGRADING, FROM UNTREATED COMBINED SEWER OVERFLOWS AND FROM ALL OTHER SOURCES

	Treatment plants		Combined sewer overflows		Separate storm sewer runoff		Other sources		
Parameter	mil lb/yr	%[a]	mil lb/yr	%	mil lb/yr	%	mil lb/yr	%	Total, mil lb/yr
BOD_5	39.9	81	7.11	14	2.1	4	0.02	0.04	49.1
COD	96.4	76	25.7	20	5.3	4	0.13	0.1	128
SS	46.7	64	17.8	24	8.8	12	0.02	0.03	73.3
HEM	6.60	57	4.70	41	0.3	3	0.002	0.02	11.6
TN	26.4	95	1.17	4	0.1	0.4	0.05	0.2	27.7
TIN	11.3	97	0.30	3	0.06	0.5	0.03	0.3	11.7
TON	16.9	95	0.87	5	0.07	0.4	0.01	0.06	17.9
TP	6.11	92	0.46	7	0.05	0.8	0.001	0.02	6.62
TSP	4.32	96	0.14	3	0.04	0.9	0.000	0.007	4.50

[a] Of total.

Table 25. TOTAL POLLUTANT LOADINGS TO JAMAICA BAY FROM WATER POLLUTION CONTROL FACILITIES PRIOR TO UPGRADING, FROM SPRING CREEK AUXILIARY WATER POLLUTION CONTROL FACILITY AND FROM ALL OTHER SOURCES

Parameter	Treatment plants mil lb/yr	Treatment plants %[a]	Combined sewer overflows mil lb/yr	Combined sewer overflows %	Separate storm sewer runoff mil lb/yr	Separate storm sewer runoff %	Other sources mil lb/yr	Other sources %	Total, mil lb/yr
BOD_5	39.9	83	6.10	13	2.1	4	0.02	0.04	48.1
COD	96.4	77	24.0	19	5.3	4	0.13	0.1	126
SS	46.7	68	13.3	19	8.8	13	0.02	0.03	68.8
HEM	6.60	64	3.49	34	0.3	3	0.002	0.02	10.4
TN	26.4	96	0.96	3	0.1	0.4	0.05	0.2	27.5
TIN	11.3	97	0.29	3	0.06	0.5	0.03	0.3	11.7
TON	16.9	96	0.67	4	0.07	0.4	0.01	0.06	17.7
TP	6.11	92	0.45	7	0.05	0.8	0.001	0.02	6.61
TSP	4.32	96	0.14	3	0.04	1	0.000	0.01	4.50

[a] Of total.

Table 26. TOTAL POLLUTANT LOADINGS TO JAMAICA BAY FROM UPGRADED WATER POLLUTION CONTROL FACILITIES, FROM SPRING CREEK AUXILIARY WATER POLLUTION CONTROL FACILITY AND FROM ALL OTHER SOURCES

	Treatment plants		Combined sewer overflows		Separate storm sewer runoff		Other sources		Total,
Parameter	mil lb/yr	%[a]	mil lb/yr	%	mil lb/yr	%	mil lb/yr	%	mil lb/yr
BOD_5	15.5	65	6.10	26	2.1	9	0.02	0.08	23.7
COD	68.0	70	24.0	26	5.3	6	0.13	0.1	97.4
SS	19.0	46	13.3	32	8.8	22	0.02	0.05	41.1
HEM	3.22	46	3.49	50	0.3	4	0.002	0.03	7.01
TN	27.2	96	0.96	3	0.1	0.4	0.05	0.2	28.3
TIN	8.92	96	0.29	3	0.06	0.7	0.03	0.3	9.30
TON	18.2	96	0.67	4	0.07	0.4	0.01	0.05	19.0
TP	5.65	92	0.45	7	0.05	0.8	0.001	0.02	6.15
TSP	4.34	96	0.14	3	0.04	0.9	0.000	0.01	4.52

[a] Of total.

Table 27. TOTAL POLLUTANT LOADINGS TO JAMAICA BAY FROM UPGRADED WATER POLLUTION CONTROL FACILITIES, FROM AUXILIARY WASTEWATER POLLUTION CONTROL FACILITIES ON ALL COMBINED SEWER OVERFLOWS AND FROM ALL OTHER SOURCES

	Treatment plants		Combined sewer overflows		Separate storm sewer runoff		Other sources		
Parameter	mil lb/yr	%[a]	mil lb/yr	%	mil lb/yr	%	mil lb/yr	%	Total, mil lb/yr
BOD_5	15.5	76	2.84	14	2.1	10	0.02	0.1	20.5
COD	68.0	76	16.7	19	5.3	6	0.13	0.1	90.1
SS	19.0	57	5.33	16	8.8	27	0.02	0.06	33.2
HEM	3.22	60	1.88	35	0.3	6	0.002	0.04	5.40
TN	27.2	97	0.776	3	0.1	0.4	0.05	0.2	28.1
TIN	8.92	96	0.240	3	0.06	0.7	0.03	0.3	9.25
TON	18.2	97	0.536	3	0.07	0.4	0.01	0.05	18.8
TP	5.65	93	0.368	6	0.05	0.8	0.001	0.02	6.07
TSP	4.34	96	0.126	3	0.04	1	0.000	0.01	4.51

[a] Of total.

the management conditions tabulated, the proportion of other pollutants (BOD$_5$, COD, SS, HEM) is about 75% of the total load and is more greatly affected by the particular management regime.

Combined sewer overflows contribute the second largest percentage of pollutants, especially oxidizable materials, suspended solids and floatables. Their contribution to coliform contamination is treated in detail in Section VIII. Separate storm runoff loadings comprise a lesser source of pollutants in that their organic pollutant loading contribution is generally under 5% and their nutrient contribution is below 1% of the total loadings. Other sources of pollutants, principally sanitary landfills, comprise a minimal (less than 1%) pollutant contribution to Jamaica Bay.

SECTION VIII

EVALUATION OF WASTEWATER MANAGEMENT ALTERNATIVES

EVALUATION CRITERIA

Environmental

The purpose of the wastewater management alternatives presented in this section is to attain the environmental quality necessary to support the desired beneficial uses of Jamaica Bay. The environmental quality requirements of existing and potential beneficial uses of Jamaica Bay were outlined in Section V. The requirements for water contact recreational activities such as swimming and wading at potential beach areas and for maintenance and propagation of desirable aquatic life can be singled out as the two most important uses that can be quantitatively related to the performance of alternative wastewater management systems.

Water quality for water contact sports requires extremely low levels of pathogenic agents to assure protection of public health. The concentration or density of total coliform organisms is a generally accepted measure or indicator of the public health character of a water. A tentative water quality criterion for bacterial quality has been set at a maximum total coliform density of 24 MPN/ml to provide safe and acceptable conditions for water contact recreation in Jamaica Bay.

For each wastewater management alternative, the quantity of total coliforms discharged to Jamaica Bay can be estimated. Moreover, using appropriate receiving water models, it is possible to predict the coliform density at a particular beach location and the reduction in usable beach time due to the discharge of a known quantity of total coliforms.

For these reasons, total coliform density was selected as the measure of the public health attributes of each wastewater management alternative and was converted to percentage of usable beach days during the summer season to produce the evaluation criterion.

Water contact recreation and general enjoyment of the Jamaica Bay waters by the residents of the area requires that the bay be aesthetically pleasing. Damaged waterfowl and fish life, odors and excessive vegetative growth should be conspicuously absent. Reduction of the discharge of deleterious materials, such as oils, greases and other floating materials, and constituents which lead to depletion of the dissolved oxygen and encouragement of undesirable and excessive vegetative growth was used as the evaluation criterion related to aesthetics.

Maintenance of a healthy biota, including fish life, requires a water quality similar to that for aesthetic enjoyment. Frequently in polluted waters low dissolved oxygen levels are responsible for fish kills and localized anoxic conditions which create malodors and other nuisances. Dissolved oxygen levels can be controlled by limiting the discharge of oxidizable materials (BOD) which place a demand upon the oxygen resources of the receiving waters. Therefore the wastewater management alternatives were evaluated on the basis of their capacity to reduce the input of BOD to the bay.

Additionally, the environmental evaluation of wastewater management alternatives must assess the environmental impact associated with the construction and operation of the proposed facilities. Evaluation of the beneficial effects and changes in the character of the Jamaica Bay ecosystem was used to screen alternatives. Negative effects due to the construction of the combined sewer overflow routing facilities, the water pollution control facilities and the effluent discharge facilities were important criteria in the evaluation process.

Economics

The costs of wastewater management alternatives are extremely important and demand careful consideration in an urban society in which there is strong competition for limited community monies. Important economic factors that determine, in part, the total cost of a program include the fixed and recurring costs associated with the wastewater management system. Capital costs of interceptors, water pollution control facilities and discharge facilities were estimated using accepted engineering principles on the basis of 1973 dollars for comparison purposes. Annual costs represent the sum of the operation and maintenance cost and the cost of borrowed funds. Similar capital recovery factors were used in the evaluation of all alternatives.

Effectiveness

The environmental and economic attributes of a wastewater management alternative cannot normally be presented in commensurate terms. Therefore the approach used in this project has been to develop recommendations based upon the cost-effectiveness of the various alternatives in achieving objectives. To be cost-effective, an alternative should provide proportionately higher environmental quality for increased expenditure of funds. Specifically, the percentage of usable beach time for Jamaica Bay and the percentage improvement in BOD concentration are expected to increase along with aesthetic quality and other factors with increasingly more expensive alternatives.

Other effectiveness criteria that were employed include the system reliability and flexibility. The reliability of combined sewer overflow management systems varies, and the consequence of mechanical or process failure should be evaluated. The selected alternative should readily accommodate unforeseen demands that may be placed upon it, such as demographic changes, upgrading of water quality standards and the availability of new treatment technology. The plan for Jamaica Bay should be flexible enough to be modified, upgraded or otherwise changed in response to future events.

In summary, recommendations from this study were based upon an evaluation of the cost-effectiveness of the various wastewater management alternatives to upgrading the water quality of Jamaica Bay.

EVALUATION METHODS

General

Implementing the above evaluation criteria is most effectively accomplished with the aid of mathematical models to predict the environmental effects of wastewater management alternatives on Jamaica Bay. Jamaica Bay is a large body of water with a surface of over 20 mi^2 and an approximate water volume of 5.25×10^{10} gal. The physical character of the bay is significantly influenced by tidal action. With a mean tidal range of approximately 5 ft and a mean depth of only 16 ft, a significant tidal exchange of 35.9% of the bay volume occurs twice daily. In spite of the apparently large wastewater dilution and flushing capability of the bay, the water quality response to storm-related inputs is limited by the tidal-dependent circulation pattern within the bay.

The majority of water movement within Jamaica Bay occurs in the dredged channels along the north and south perimeters. These channels are up to 40 ft deep and 1,000 ft wide. Virtually all stormwater runoff and sewage treatment plant effluents are transported in these channels, past potential beach areas, and out Rockaway Inlet to the New York Bight. Moreover, these discharges reach the main channels via side channels or basins, such as Paerdegat Basin and Spring Creek, which enter the bay along its perimeter in close proximity to potential beach areas. The water quality at a beach following a particular storm will be dependent upon a number of factors including (1) the magnitude of pollutants discharged from separate and combined sewers and water pollution control facilities, (2) the initial dilution available in the side channels, (3) the mechanism by which the side channel input spreads across and is diluted in the main channel, (4) the apparent dilution due to decay or disappearance of pollutant concentration and (5) the direction and speed of the tidal currents in the main channel.

A receiving water quality model was developed to incorporate these factors and enable the prediction of the improvement in Jamaica Bay water quality from implementation of alternative combined sewer overflow management systems. One water quality model was developed to predict coliform bacteria densities at potential beaches after storms of different magnitudes and relate these to the percent of the time the beach would be usable during the summer season under different management alternatives. A second water quality model was developed to predict the expected reduction in BOD concentrations that would occur in the bay from implementation of alternative wastewater and combined sewer overflow management systems. Both of these models require an accurate estimation of the magnitude of pollutants discharged from each drainage basin for a given storm. These estimates were based upon extensive data collection efforts and an urban runoff model developed for the project.

Modeling efforts were conducted in parallel with a two-dimensional dynamic water quality simulation model developed by the New York City Rand Institute [9]. The Rand model was linked to the urban runoff model developed in this project and produced a time history of pollutant concentration at any point within the bay resulting from a storm of given intensity and duration occurring at a particular time within the tidal cycle. At the present time (1974), the Rand model has been used to simulate coliform concentrations for three storm patterns.

Valuable insight into the response of Jamaica Bay to stormwater inputs can be gained from simulations made with the Rand model. In the northern part of Jamaica Bay the combined sewer overflows from Paerdegat Basin, Fresh Creek, Hendrix Basin, Spring Creek and Bergen Basin are discharged into channels and basins of various lengths and capacities, rather than directly into the bay. It typically takes several hours for the combined sewer overflows to flow and disperse to the mouths of their channels and into the bay. For storms which are coincident with high tide, the combined sewer overflows are carried out of these basins with the first ebbing tide and dispersed over a wide area very quickly because of the transport that occurs during the next flooding tide. In contrast, the discharge from a storm that occurs at low tide is held back in the channels by the flooding tide and does not get carried out into the bay until the next ebbing tide. It was observed that the coincidence of low tide with the start of the rainstorm, and subsequent storage in the channels, leads to an increase in coliform bacteria concentrations over a larger area of the bay for a longer duration than with the storm beginning at high tide. In the southern portion of the bay, a storm occurring at high tide holds back some of the runoff in the Rockaway sewer system and results in only a small overflow to the bay because the interceptor can handle the additional load. Moreover, during heavy rainfall, the interceptor is pumped down directly to the bay, bypassing treatment. A storm occurring at low tide is also the worst case in the southern part of the bay because a very intense discharge occurs at the Rockaway combined sewer overflow and the incoming flooding tide carries the discharge immediately toward the back of the bay.

Urban Runoff Model

Quantity Component--

Data obtained during this project have shown the rainfall-runoff relationship to be a linear process, so that it was possible to use a computationally efficient linear model to predict the coliform loadings to the bay from a given storm. A schematic diagram showing the various components of the precipitation-overflow sequence in an urban drainage system is shown in Figure 64. The figure also indicates the input/output and computational steps involved in the urban runoff model. According to linear system theory, the input (rainfall)/output (overflow) relationship may be obtained by convolution of the effective input and the instantaneous unit hydrograph. In computation, a summation form of the convolution integral is used to compute the direct runoff hydrograph from the pulsed inputs--effective rainfall hyetograph and a short-duration unit hydrograph.

Measured hydrographs for each sub-basin from isolated short-duration storms were used to compute unit hydrographs. A basic 20-min hydrograph was constructed by averaging several unit hydrographs of 15- to 20-min duration. This basic unit hydrograph has been used to derive direct runoff hydrographs from computed effective rainfall hyetographs. In order to determine the effective rainfall hyetograph from the total rainfall hyetograph, the "loss" function for the drainage basin must be formulated. Loss parameters include interception, evaporation, infiltration, depression storage, etc. The relative importance of each loss component depends principally upon the physical characteristics of the land surface. For example, in most urban areas, rainfall intercepted by vegetation and lost through evaporation during precipitation is rarely of importance. Investigations have shown that infiltration approaches a steady minimum rate after 1 or 2 hr. Infiltration is also affected by antecedent precipitation. High-intensity rains of short duration occurring after a dry spell often produce little, if any, runoff. A standard infiltration curve was used to compute losses due to infiltration. Depression storage for different land surfaces depends on their roughness and slope. For the model employed in this investigation, loss parameters are each assigned to a function which generates an effective rainfall hyetograph from any total rainfall hyetograph. Land-use distribution and imperviousness of each surface are the two factors used to estimate the loss parameters. These input values were adjusted by comparing computed with measured direct runoff hydrographs.

Comparisons between the model output and actual monitoring data are presented in Appendix C. Good agreement was achieved in spite of several unknowns, including the initial amount of storage in the sewer, the actual rainfall distribution on the basin and the complex relationship between the overflow process and the bay water level.

Quality Component--

An important adjunct to the quantity model is the model which predicts the quality, i.e., coliform concentration in MPN/ml, of the combined sewer overflow. The time history of combined sewer overflow coliform concentration was found to be affected by dilution, scouring and surface washing. The elements of the quality model are shown in Figure 64. The following equation was derived to predict the coliform concentration at time t:

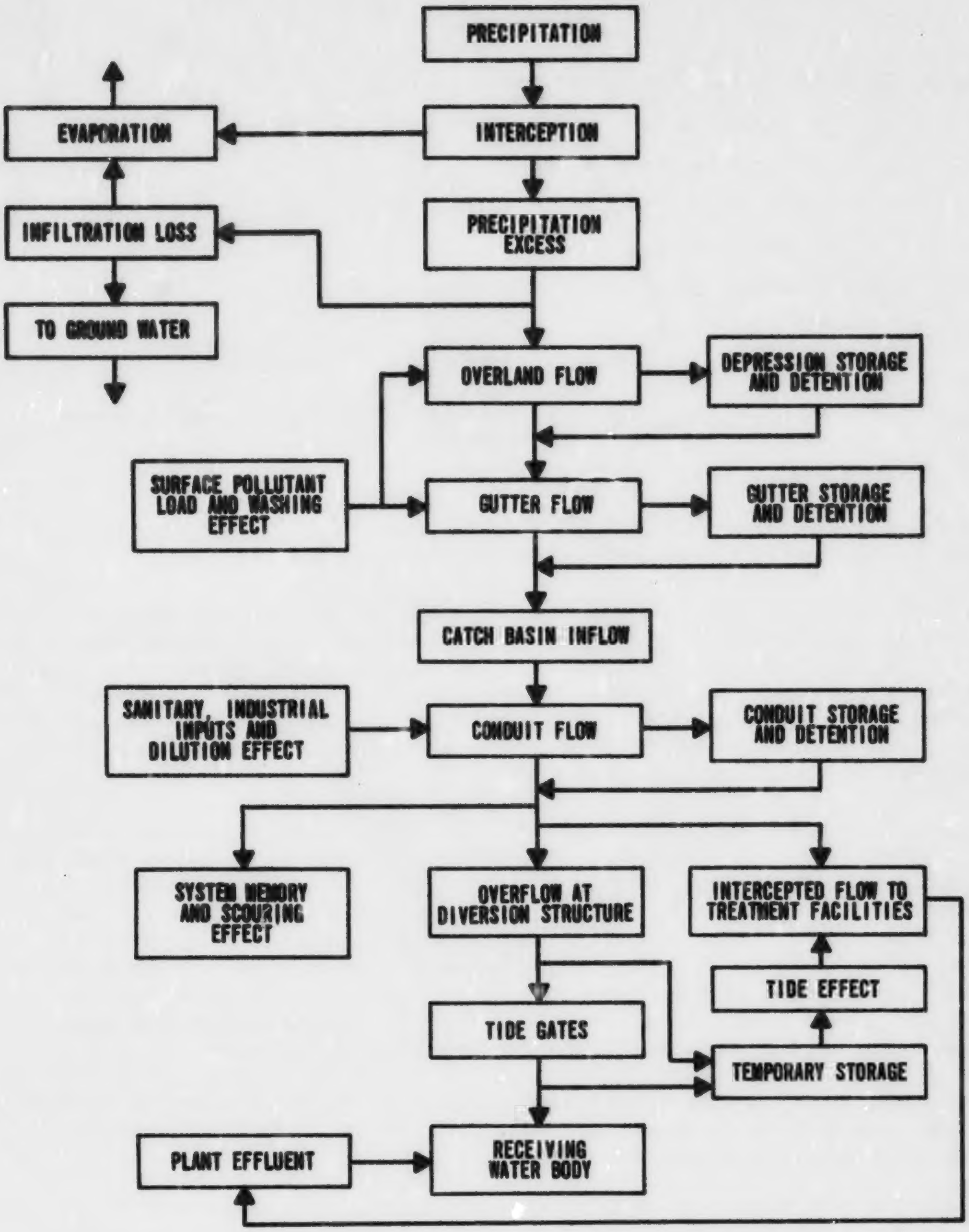
PRECIPITATION
EVAPORATION
INTERCEPTION
INFILTRATION LOSS
PRECIPITATION EXCESS
TO GROUND WATER
OVERLAND FLOW
DEPRESSION STORAGE AND DETENTION
SURFACE POLLUTANT LOAD AND WASHING EFFECT
GUTTER FLOW
GUTTER STORAGE AND DETENTION
CATCH BASIN INFLOW
SANITARY, INDUSTRIAL INPUTS AND DILUTION EFFECT
CONDUIT FLOW
CONDUIT STORAGE AND DETENTION
SYSTEM MEMORY AND SCOURING EFFECT
OVERFLOW AT DIVERSION STRUCTURE
INTERCEPTED FLOW TO TREATMENT FACILITIES
TIDE EFFECT
TIDE GATES
TEMPORARY STORAGE
PLANT EFFLUENT
RECEIVING WATER BODY

Figure 64. Components of urban hydrological system

$$C_t = \left[\frac{C_D\, q_D}{q_D + q_S} \right]_t + \alpha S (q_S + q_D)_t^{n-1} + W(q_S)^{k-1} \qquad (1)$$

where C_D = dry-weather coliform concentration;

q_D = dry-weather flow rate;

q_S = wet-weather flow rate;

S = coefficient related to storage factor and sewer slope;

$\alpha = 0$ when $t > t_{max}$ or

$\alpha = 1$ when $t \le t_{max}$;

t_{max} = time of hydrograph peak;

n = empirical coefficient;

W = coefficient varying with streat cleaning frequency, basin geometry and population density; and

k = varies from 1.5 to 2.0.

Equation (1) contains three terms corresponding respectively to the dilution effects, scouring effects and surface washing effects.

The dilution term has a characteristic shape of an inverted Gaussian curve (shape depending upon the storm hydrograph) with each end asymptotically approaching the dry-weather concentration. The scouring term rises exponentially as the direct runoff hydrograph rises but drops sharply when the available concentration is exhausted. The value of $n = 3$ was generally used. The street gutter contribution has the same shape as the overflow hydrograph.

For a typical storm, the time history of coliform concentration, C_t, will exhibit a W-shaped curve. Coliform data taken at the five combined sewer overflow monitoring sites have confirmed this configuration. The coefficients S and W are functions of sewer and surface conditions at the time of the storm. The data indicate that although S and W vary from storm to storm they do not influence the basic shape of the coliform curve. Most of the computed coliform curves are well within the 95% confidence limits of the measured values. Comparison of the model output and actual monitoring data are presented in Appendix C.

The urban runoff quality model was extended to enable production of suspended solids concentration as a function of time. Further documentation is given in Appendix C.

Receiving Water Model for Coliform Density

Input--

Coliform Loadings. The receiving water coliform model utilized data generated by the urban runoff model for the total coliform loading (MPN) to the bay from each drainage basin as a function of the total storm rainfall depth [10]. Figure 65 shows these relations. The coliform loading from separately sewered areas for different storm sizes was computed using the drainage area, a runoff coefficient of 0.65 and an average coliform concentration of 9,000 MPN/ml.

Currents. Water circulation in Jamaica Bay is largely determined by tidal action because the net advective flow is less than 1% of the tidal exchange. Moreover the distance traveled by a combined sewer overflow on the flood and the ebb tide is significant, and most of the overflows will affect two or more beaches during one tidal cycle. Tidal currents in the main channels range from 2 feet per second (fps) into the bay to 2 fps out of the bay, except in the Grassy Bay area where the maximum currents are on the order of 0.5 fps.

Coliform Disappearance Rate. Coliform disappearance studies were conducted during the course of the project to determine the rate of disappearance in the receiving water environment. As a result of these studies, it was found that 90% of the coliforms disappeared within 24 hr, providing a rate constant of 0.10 day^{-1}.

Computational Procedure--

Dilution Calculations. The coliform loadings from the combined sewer overflows, runoff from separately sewered areas and the effluent from the dry-weather flow treatment facilities will experience an initial dilution in the side channel or basin. The resulting concentration, a function of the basin volume, will then disappear at the exponential rate of 0.10 day^{-1} for the duration of the residence time in the basin. The residence time is dependent upon the overflow duration and the tidal conditions and ranges from several hours in the Spring Creek channel to approximately 16 hr in Paerdegat Basin.

The mixing and transport of the basin waste loads with the main channel flow was modeled in a fashion similar to wastewater diffusion from an ocean outfall. The effects of initial mixing with a portion of the main channel flow followed by lateral spreading across the channel and combined with dilution due to disappearance can be expressed in mathematical form to give the resulting concentration C_1 at a downstream beach as:

$$C_1 = C_0 e^{-k_1 t} \operatorname{erf}\left[\frac{b}{4}\sqrt{\frac{1}{E_y t}}\right] \qquad (2)$$

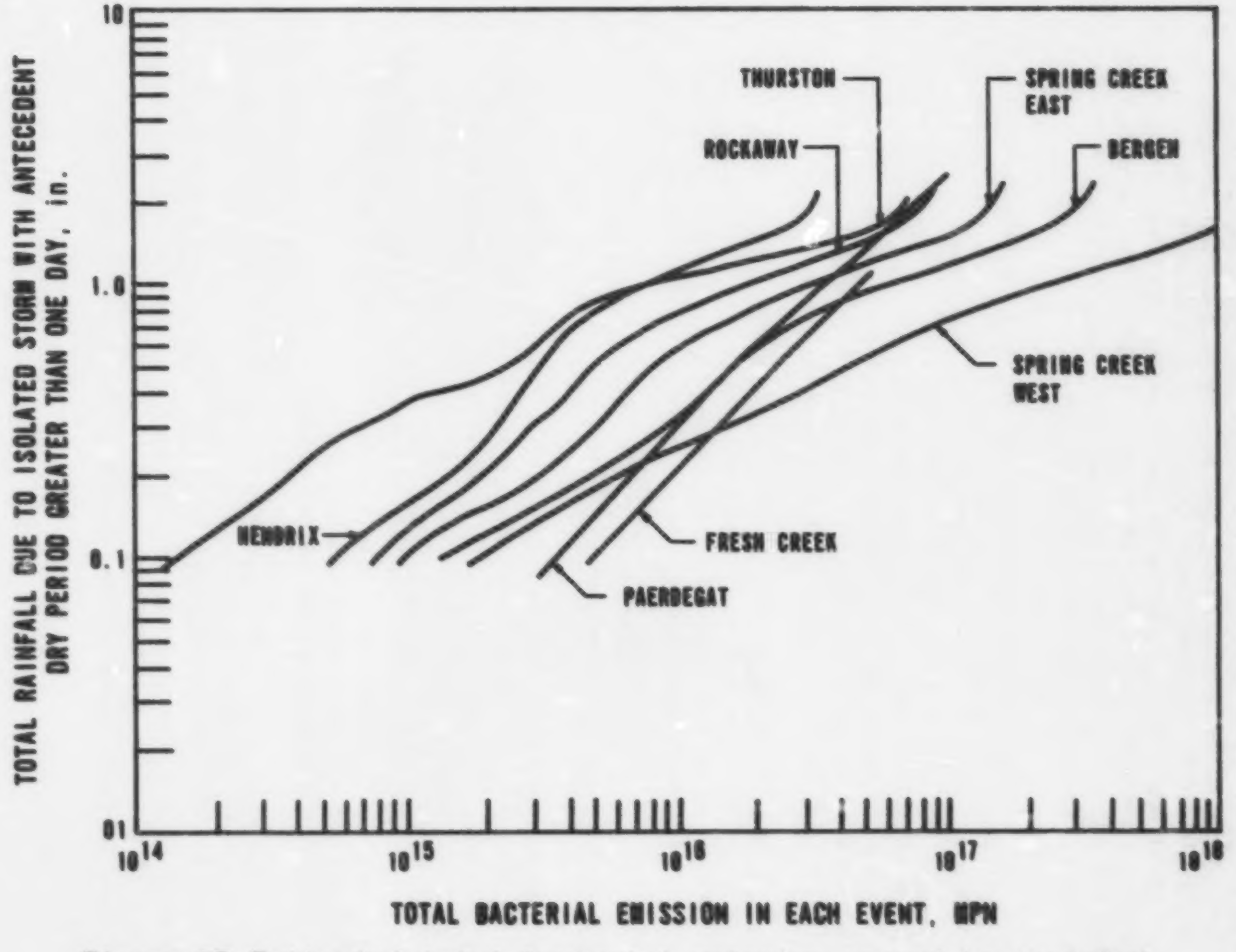

Figure 65. Estimated total bacterial emission caused by isolated storms from each drainage system

where C_0 = initial concentration of basin flow in the main channel, MPN/ml;

k_1 = disappearance rate, day^{-1};

t = travel time to beach, day;

b = initial width of basin flow field in main channel, ft;

E_y = coefficient of lateral diffusion, ft^2/day; and

erf = error function.

Computations were made for three storms--0.10, 0.50 and 1.0 in.--and for conditions corresponding to the beginning of the storm occurring at low water and at high water. The resulting coliform concentrations were predicted at the four most promising potential beach sites on Jamaica Bay.

Usable Beach Days. It is helpful to express the results of analysis in terms of the percentage of time during which the beach would be usable, i.e., water quality standards for coliform are achieved. A frequency distribution of the number of storms during a summer season (May 1 to September 30) is shown in Figure 66. By averaging the results of the predicted coliform concentrations at each beach and each storm for ebbing and flooding tide and assuming a disappearance from the maximum concentration of 0.90 day^{-1}, the length of unusable beach time for each isolated storm event was computed. Finally, with the storm frequency distribution, and given that there are 139 possible usable beach days in a summer season (May 15 to September 30), the percentage of usable beach time at each beach was computed for selected wastewater management alternatives. The analysis thus displayed the effects on usable beach days as various combined sewer overflows were brought under control.

Verification. The receiving water coliform model results were compared to results of the Rand model simulations for two storms and four beach sites. As is documented in Appendix C, predicted concentrations were usually within 25%. Considering the nature of the problem, this agreement was deemed adequate for the objectives of the coliform model.

Receiving Water Quality Model for BOD

Inputs--

The mass discharges of BOD to Jamaica Bay for various wastewater management alternatives are presented in Tables 24, 25, 26 and 27. The response of the bay to BOD inputs in the winter is different from that in the summer; i.e., the rate of utilization of BOD is less in the winter, causing winter BOD concentrations to be higher. The inputs to the bay are also seasonal, with a higher proportion of the combined sewer overflow occurring in the summer. This is due to the type of rainfall; i.e.,

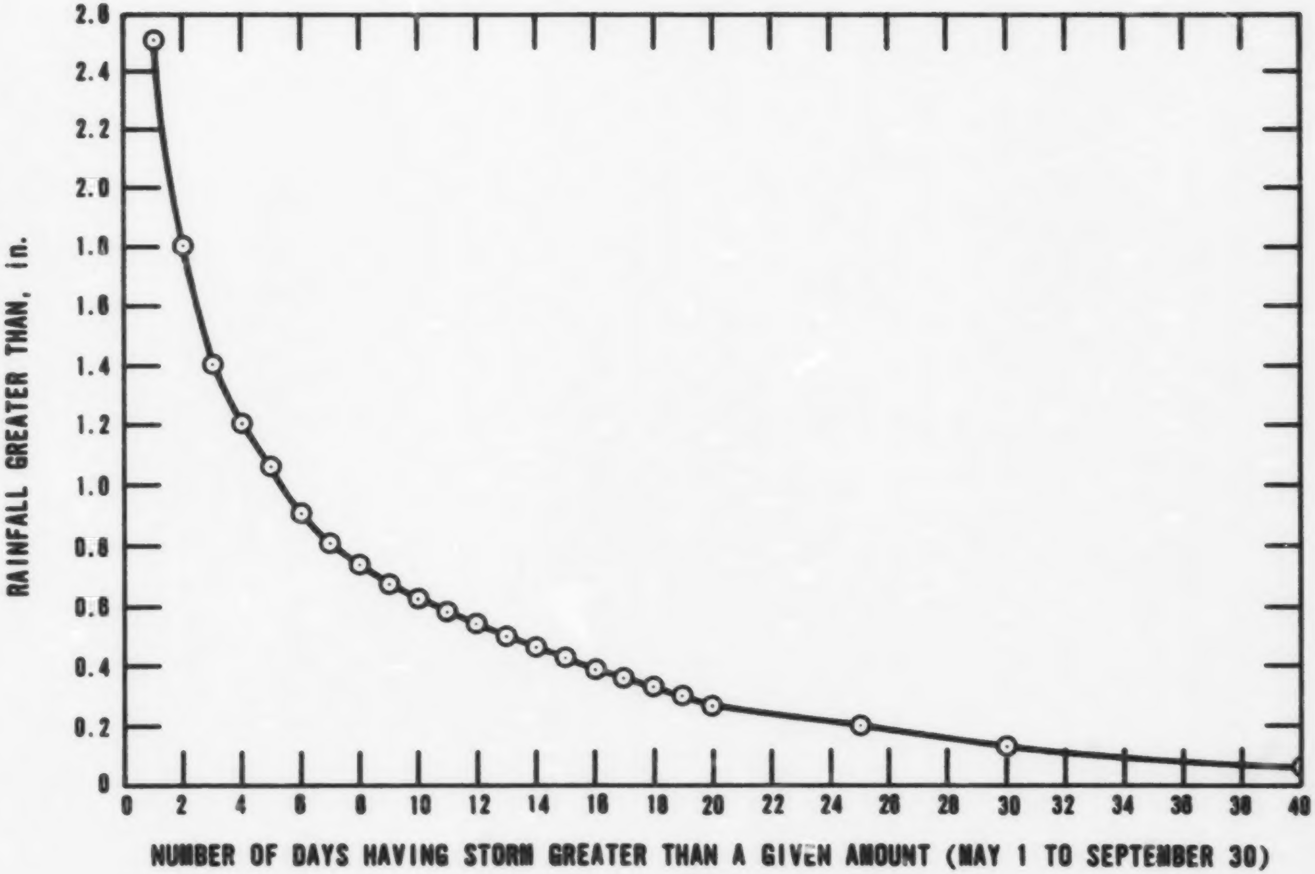

Figure 66. Summer storm duration curve for New York City

summer thunderstorms cause a higher combined sewer overflow than that caused by a low-intensity winter rain or snowfall.

Computation--

A model was developed to show the seasonal improvement in the receiving water BOD_5 concentration under different combined sewer overflow management alternatives. The general approach of the BOD model was to compute resulting concentrations on the basis of a seasonal mass balance of sources and sinks. The model was derived from the one-dimensional, time-dependent differential equation that expresses BOD_5 concentration as a function of inputs, dilution, diffusion and sink terms. Because, in a seasonal mass balance, the time and spatial variations in concentration average out, the resulting mass balance can be expressed as:

$$(k_2 + k_3)L = R_a \tag{3}$$

where k_2 = BOD exertion rate constant;

k_3 = BOD removed/added by sedimentation or resuspension;

L = ultimate BOD = 1.5 times BOD_5; and

R_a = rate of BOD_5 addition.

The BOD model was calibrated to determine the parameter k_3 for summer (June, July, August) and winter (December, January, February). The average BOD_5 of Jamaica Bay was computed from Figures 21 and 22 to be 2.7 mg/l in the summer and 4.7 mg/l in the winter. This was converted to the average total mass of BOD, L, indigenous to the bay during these seasons. The rate constant k_2 ($0.13\ day^{-1}$ at 20°C) was adjusted for summer and winter temperatures, and the rate of BOD_5 addition, R_a, was computed from data presented in Section VII. These data enabled estimation of k_3; the computed values are given in Appendix C.

With k_2 and k_3 known, it is possible to use Equation (3) to compute a new L associated with the loading rates, R_a, for each alternative wastewater management program. The total mass L can be converted to a BOD_5 concentration for evaluation of effects of the alternatives on Jamaica Bay water quality.

WASTEWATER MANAGEMENT ALTERNATIVES

There are three basic methods for upgrading the water quality in Jamaica Bay. These are to upgrade the performance characteristics of the four major sewage treatment facilities, to provide some form of treatment for the combined sewer overflows and to route the discharges to a more favorable location such as a submarine outfall discharge to the ocean. From these three techniques a total of 11 alternative combinations was developed for wastewater management in Jamaica Bay. The essential features of the alternatives are presented in Table 28. The locations of

Table 28. WASTEWATER MANAGEMENT ALTERNATIVES FOR JAMAICA BAY

Alternative	Treatment provision							Disposal location	
	WPCF treatment		AWPCF location[a]						
	Prior[b]	Upgraded[c]	Spring Creek	Paerdegat	Fresh Creek	Bergen	All others	Bay	Ocean
1	X							X	
2	X		X					X	
3		X	X					X	
4		X	X	X				X	
5		X	X		X			X	
6		X	X			X		X	
7		X	X	X	X			X	
8		X	X	X	X	X		X	
9		X	X	X	X	X	X	X	
10		X	X						X
11		X	X						X

[a] All treatment levels comparable to Spring Creek Auxiliary Water Pollution Control Facility.
[b] Effluent quality prior to 1970.
[c] Estimated effluent quality from upgraded (step-aeration) facilities.

the treatment facilities are shown in Figures 67 and 68. The effects of the alternatives, including the associated receiving water quality and the costs, are presented in a following subsection.

Alternative 1

Alternative 1 is included for reference and represents the conditions at the Coney Island, 26th Ward, Jamaica and Rockaway sewage treatment facilities prior to the conduct of this study with no combined sewer overflow treatment. In the cost analysis, Alternative 1 was assigned a zero cost so that additional investments would be relative to this base level.

Alternative 2

The construction of the Spring Creek Auxiliary Water Pollution Control Facility (see Figure 67) was completed in 1972, and treatment of combined sewer overflows from the Spring Creek East and Spring Creek West basins began. Details of the facility are presented in Section VII. Basically the plant acts as a holding basin for later treatment at the 26th Ward facility for the volume of a storm of depth equal to 0.25 in. (ignoring in-sewer storage) and provides treatment approximately equivalent to primary treatment (see Figure 63 for predicted aggregate pollutant removals) for storms larger than 0.25 in. It is included in the evaluation so as to isolate the cost-effectiveness of this single combined sewer overflow treatment facility.

Alternative 3

Upgrading of three of the dry-weather sewage treatment facilities is well underway to provide conventional step-aeration secondary-level treatment (26th Ward, Jamaica and Rockaway). Upgrading of the fourth, Coney Island, is pending release of impounded Federal funds. Modifications include increased carbonaceous oxidation, improved chlorination facilities and expanded sludge handling capacity at each of the four facilities. Alternative 3 also includes the Spring Creek auxiliary facility. Successive alternatives build upon Alternative 3.

Alternative 4

Alternative 4 provides combined sewer overflow treatment for Paerdegat Basin in addition to the facilities presented in Alternative 3. A facility similar to the Spring Creek facility would be constructed with the size increased over that provided for Spring Creek to handle the larger flow volumes from Paerdegat Basin. Discharge would be at the upper end of Paerdegat Basin, as shown on Figure 67.

Alternative 5

The combined sewer overflow discharge from Fresh Creek is significant

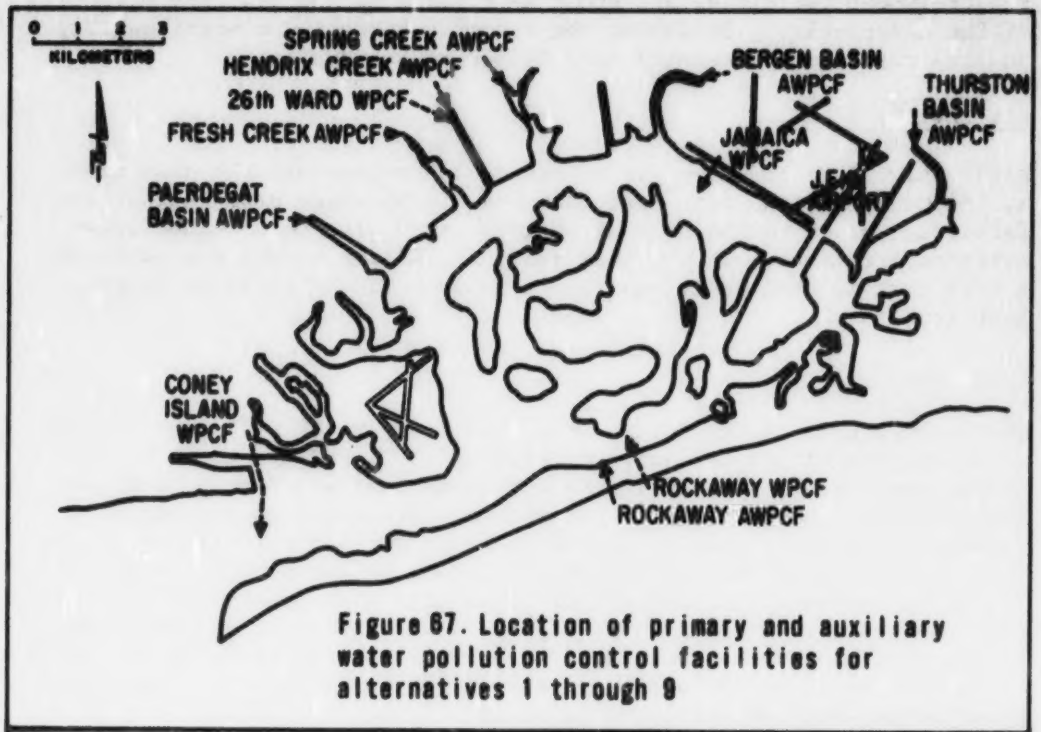
0 1 2 3
KILOMETERS
N
SPRING CREEK AWPCF
HENDRIX CREEK AWPCF
26th WARD WPCF
FRESH CREEK AWPCF
PAERDEGAT BASIN AWPCF
BERGEN BASIN AWPCF
JAMAICA WPCF
THURSTON BASIN AWPCF
J.F.K. AIRPORT
CONEY ISLAND WPCF
ROCKAWAY WPCF
ROCKAWAY AWPCF

Figure 67. Location of primary and auxiliary water pollution control facilities for alternatives 1 through 9

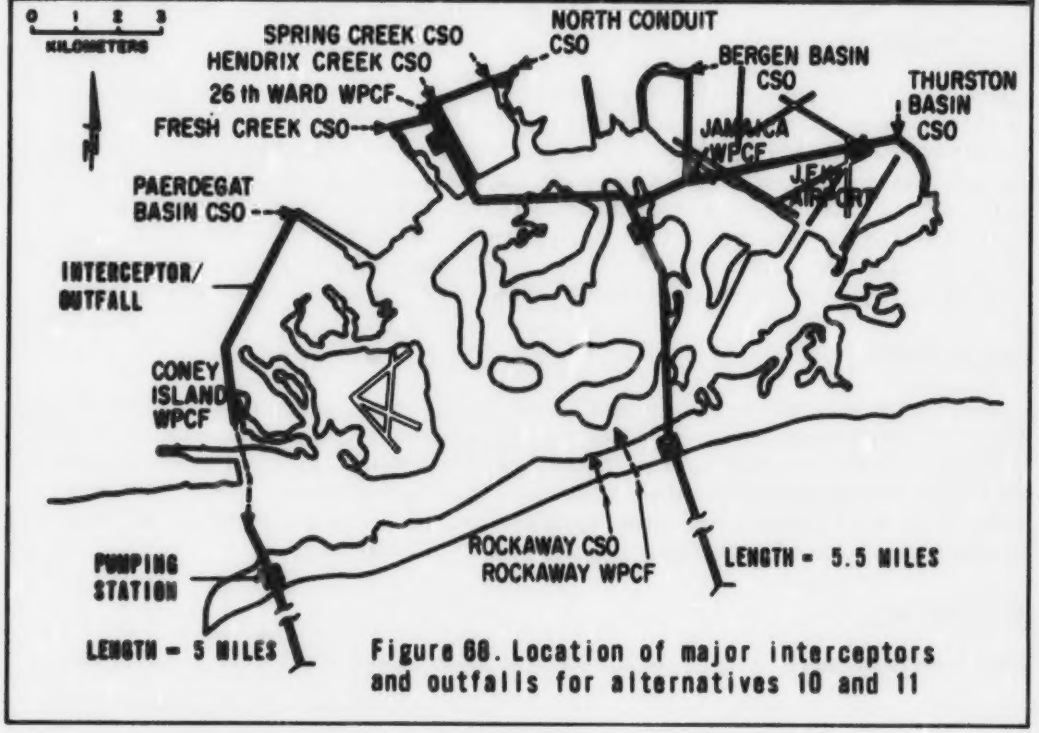
0 1 2 3
KILOMETERS
N
SPRING CREEK CSO
HENDRIX CREEK CSO
NORTH CONDUIT CSO
26th WARD WPCF
FRESH CREEK CSO
BERGEN BASIN CSO
JAMAICA WPCF
THURSTON BASIN CSO
J.F.K. AIRPORT
PAERDEGAT BASIN CSO
INTERCEPTOR/ OUTFALL
CONEY ISLAND WPCF
PUMPING STATION
LENGTH = 5 MILES
ROCKAWAY CSO
ROCKAWAY WPCF
LENGTH = 5.5 MILES

Figure 68. Location of major interceptors and outfalls for alternatives 10 and 11

due primarily to its location near potential beach sites, and Alternative 5 would incorporate an auxiliary facility to serve the Fresh Creek area, in addition to facilities described in Alternative 3. Discharge would be at the plant site at the upper end of Fresh Creek Basin, as shown on Figure 67.

Alternative 6

Another significant combined sewer overflow occurs from Bergen Basin. Alternative 6 would provide combined sewer overflow treatment facilities for Bergen, Spring Creek West and Spring Creek East basins. A major portion of the facilities necessary to treat the Bergen Basin combined sewer overflow is related to the construction of interceptors to collect the overflows in Bergen Basin and transport them to a suitable single point for combined treatment and discharge to Jamaica Bay, as shown on Figure 67.

Alternative 7

A logical combination of the preceding alternatives is to combine Alternatives 4 and 5. Alternative 7 thus includes combined sewer overflow treatment for Paerdegat, Fresh Creek, Spring Creek West and Spring Creek East basins.

Alternative 8

The combination of Alternatives 4, 5 and 6 has been made to form Alternative 8. Combined sewer overflow treatment in auxiliary facilities would be provided for Fresh Creek, Paerdegat, Bergen, Spring Creek West and Spring Creek East basins. The type of treatment and discharge points would be the same as for Alternatives 4, 5 and 6.

Alternative 9

All of the combined sewer overflows tributary to Jamaica Bay would receive treatment in auxiliary facilities under Alternative 9. In addition to those facilities provided in Alternative 8, auxiliary facilities providing treatment similar to that at the Spring Creek facility would be constructed for Hendrix, Thurston and Rockaway basins. Discharge points would be located at the upper end of Hendrix Creek, at Thurston Basin and near the Rockaway sewage treatment facility, as shown on Figure 67.

Alternative 10

A marine outfall system was developed as an alternative to evaluate the cost-effectiveness of removing the four dry-weather sewage treatment facility effluents and the combined sewer overflow discharges from Jamaica Bay. It was found least expensive to construct two outfalls, one an extension to the Coney Island outfall and one serving the other three sewage treatment facilities. Additionally, an interceptor network was included to route the combined sewer overflows and the water pollution control facility effluents to the outfall. The conduit system and pumping station locations are shown on Figure 68. The Coney Island outfall would be extended 5 mi to a depth of 50 ft in the Atlantic Ocean, and the second outfall would be 5.5 mi in length, discharging at a depth of 50 ft. These lengths and depths were based upon the dilution required to insure that the water quality standards of 24 MPN/ml would be achieved at Rockaway Beach. In addition, chlorination facilities would be provided to disinfect the combined sewer overflow prior to discharge. The total capacity for the two-outfall system would be 1,855 mgd, which would provide capacity for 150% of the average dry-weather flow plus the peak runoff from a rainfall intensity of 0.15 in./hr. All combined sewer overflows resulting from runoff from rainfall in excess of 0.15 in./hr would be bypassed directly without treatment to Jamaica Bay. It is estimated that the two-outfall system would capture 100% of the dry-weather sewage treatment facility effluents and 46% of the annual pollutant load from the combined sewer overflows.

Alternative 11

The capacity of the marine outfall system of Alternative 10 has been increased to form Alternative 11. The physical layout would be the same as shown on Figure 68. The total hydraulic capacity of the two-outfall system would be 7,860 mgd, which would provide capacity for 150% of the dry-weather flow plus the peak runoff from a rainfall intensity greater than 1.0 in./hr. Seldom, if ever, would a rainfall intensity greater than 1.0 in./hr occur simultaneously on every drainage basin tributary to Jamaica Bay and persist longer than the time of concentration. Thus the outfall system of Alternative 11 would capture 100% of the water pollution control facility effluent, and it can be assumed that it would also capture 100% of the annual pollutant load from the combined sewer overflows.

POLLUTANT LOADINGS FOR EACH ALTERNATIVE

The total pollutant loadings from all sources for each alternative wastewater management system are summarized in Table 29. The largest source of these loadings is the effluent from the dry-weather sewage treatment facilities. Alternatives 1 and 2 correspond to the treatment conditions prior to upgrading of any of these facilities, and Alternatives 3 through 11 reflect reduced waste loads expected from all four upgraded facilities. The projected average total waste loadings from combined sewer overflows and auxiliary facilities are the second most important source of pollutants for each alternative. Complete treatment of combined sewer overflows (Alternative 9) provides a 60% reduction in BOD_5 loading over the untreated situation. Total coliform density from each auxiliary facility is expected to be in the order of 1 MPN/ml. This is greatly reduced from the untreated discharges, which are in the order of 10^5 MPN/ml. Other sources which are included in

Table 29. AVERAGE TOTAL POLLUTANT LOADINGS TO JAMAICA BAY FOR ALTERNATIVE WASTEWATER MANAGEMENT PROGRAMS

(mil lb/yr)

Parameter	Alternative										
	1	2	3	4	5	6	7	8	9	10	11
BOD_5	49.1	48.1	23.7	22.6	23.2	22.8	22.1	21.2	20.5	5.4	2.1
COD	128	126	97.1	94.2	96.1	95.4	93.2	91.5	89.8	18.3	5.4
SS	73.3	69.0	41.3	40.0	39.7	38.6	38.4	35.6	33.4	16.0	8.8
HEM	11.6	10.4	7.01	6.76	6.65	6.40	6.40	5.79	5.40	2.2	0.3
TN	27.7	27.5	28.3	28.4	28.3	28.3	28.2	28.2	28.1	0.6	0.1
TIN	11.7	11.7	9.30	9.28	9.29	9.29	9.27	9.26	9.25	0.2	0.1
TON	17.9	17.7	19.0	19.0	19.0	19.0	18.9	18.9	18.8	0.4	0.1
TP	6.62	6.61	6.15	6.10	6.14	6.14	6.09	6.08	6.07	0.3	0.1
TSP	4.50	4.50	4.52	4.52	4.52	4.52	4.52	4.51	4.51	0.1	0.1

Table 29 are discharges from sanitary landfills and pollutant loadings contributed by runoff from separately sewered areas. These contributions will remain the same under all alternatives considered.

The pollutant loadings for each alternative in terms of total coliform concentration from the dry-weather sewage treatment facilities and the combined sewer overflow treatment facilities are given in Table 30.

Table 30. ASSUMED COLIFORM CONCENTRATION IN EFFLUENTS FROM WATER POLLUTION CONTROL FACILITIES

(MPN/ml)

Location	Prior treatment		Upgraded treatment	
	Concentration	Applies to alternative	Concentration	Applies to alternative
26th Ward	5,000	1,2	1	3-11
Jamaica	1	1,2	1	3-11
Rockaway	1	1,2	1	3-11
Coney Island	1	1,2	1	3-11
Paerdegat Basin	varies[a]	1,2,3,5,6	1	4,7-9
Fresh Creek	varies	1,2,3,4,6	1	5,7-9
Hendrix Basin	varies	1-8,10	1	9
Spring Creek	varies	1,2	1	3-11
Bergen Basin	varies	1-5,7,10	1	6,8,9
Thurston Basin	varies	1-8,10	1	9
Rockaway Basin	varies	1-8,10	1	9

[a] Function of storm, basin characteristics.

The loadings for the basins not served by an auxiliary facility in a particular alternative were derived from the urban runoff quality model. For Alternative 10 the loadings from combined sewered areas were proportional to storm size and varied from no overflow for storms of depth 0.10 in. to overflow (pollutant loading) of 74% of the runoff volume for storms of depth 1.0 in. The loading from these sources for each alternative is shown in Table 30. In addition, a concentration of 9,000 MPN/ml in storm runoff from separately sewered areas was assumed for all alternatives. In order to evaluate the effects of alternatives on the receiving water quality, the contribution of other natural sources was included. Estimates of the equivalent total waste loading from marsh grass decomposition in Jamaica Bay were made, and the value of 11.5×10^6 lb BOD_5/yr was used to compute the natural background concentration of BOD_5 in Jamaica Bay. This loading is not included in Table 29 as it would be of the same magnitude for all alternatives considered. A background concentration of 10 MPN/ml total coliforms was also used in the evaluation of all alternatives.

EFFECTS OF ALTERNATIVES

Recreation Day Profiles

The coliform model was used to analyze the effects on Jamaica Bay water quality for each of the 11 wastewater management alternatives. Predicted concentrations for each alternative under different storm sizes were computed and converted to the number and percentage of usable beach days annually. There are 139 potential usable beach days during the period May 15 to September 30.

The results of the analysis for each alternative are presented in Figure 69 for the four potential beach sites and in Figure 70 for all beaches combined. Beach 1 is located along the bayfront of Barren Island starting at the Mill Basin outlet. Beach 2 is located along the Island Channel at Canarsie Park between Paerdegat Basin and Fresh Creek. Beach 3 is located between Beach 2 and Fresh Creek along the Island Channel. Beach 4 is located along Island Channel between the Spring Creek outlet and Shellbank Basin.

Alternative 1 represents prior conditions and shows that Beach 1 would be usable 93% of the time and that Beaches 2, 3 and 4 would be usable approximately 67% of the time. Construction of the Spring Creek auxiliary facility (Alternative 3) produced marked improvement at Beaches 2, 3 and 4. The upgrading of the four sewage treatment facilities, particularly the 26th Ward facility, and the large improvement in Alternative 4 over Alternative 3 shows that Paerdegat Basin has a significant impact at Beaches 2 and 3, more so than just adding facilities at Fresh Creek or Bergen Basin (Alternatives 5 and 6). Alternatives 7, 8 and 9 show increasing usable beach days as additional combined sewer overflow treatment facilities are added to the management plan. Only Alternatives 9 and 11 will provide total usage at all beaches all of the time.

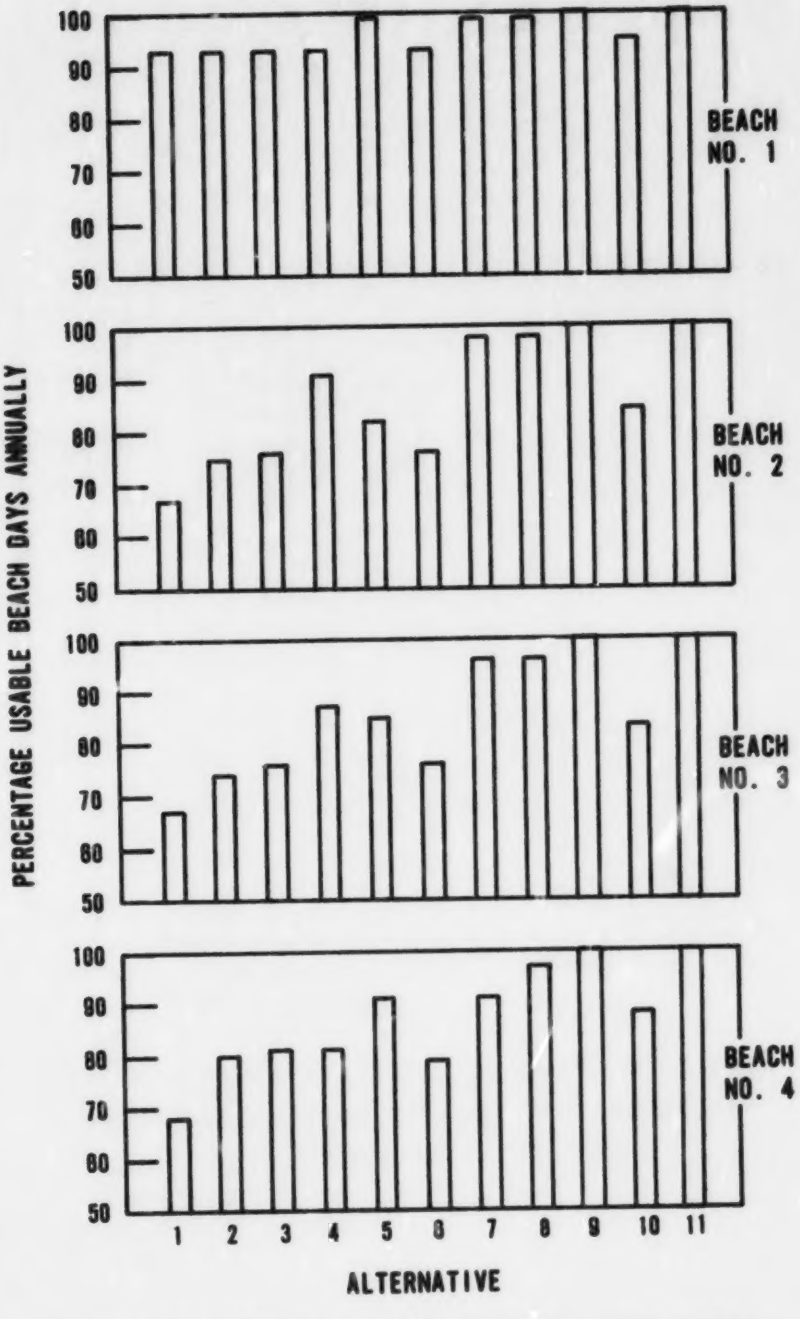

Figure 69. Effect of alternative wastewater management programs on usable beach days for each potential beach

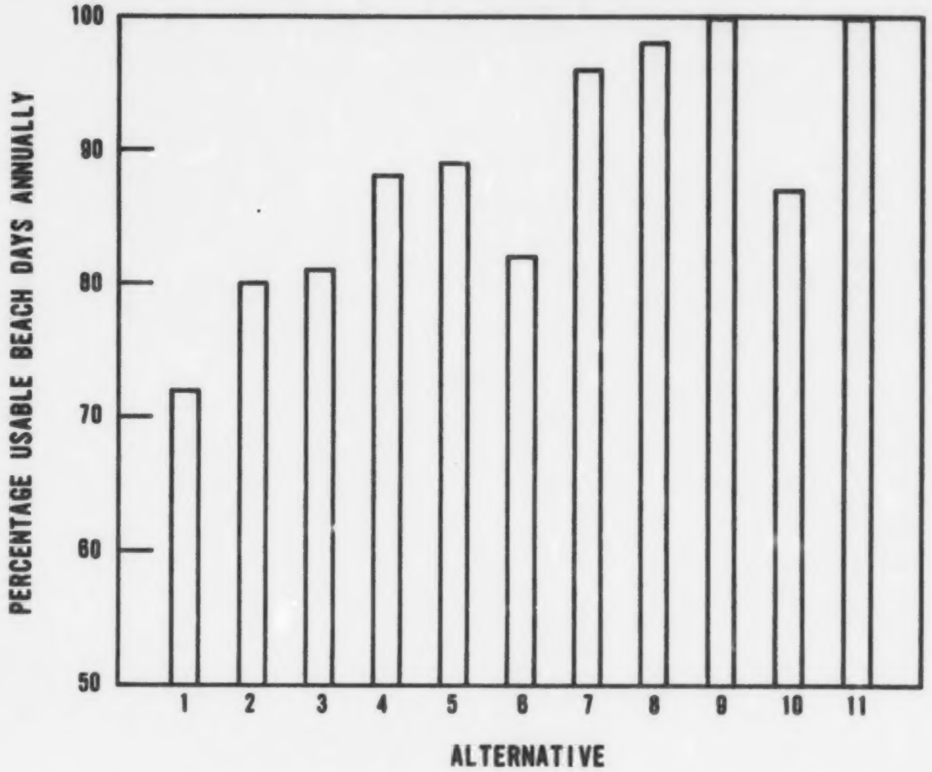

Figure 70. Effect of alternative wastewater management programs on usable beach days for all potential beaches

Under Alternatives 9 and 11 the only untreated source of coliform would be urban runoff, which by itself would not lower water quality below the standards. Alternative 10 shows a lower usable beach time than in Alternatives 4, 5, 7, 8 or 9 because significant amounts of combined sewage would have to be bypassed as a result of high flow rates associated with the larger storms. Alternatives 9 and 11 thus produce the best percentage of usable beach days in Jamaica Bay, followed in decreasing order by Alternatives 8, 7, 5, 4, 10, 6, 3, 2 and 1.

Receiving Water Responses

The BOD model was used to develop the predicted receiving water quality for each alternative wastewater management program. The results are presented in Figure 71 for average summertime and average wintertime conditions. Marked improvement in the BOD_5 concentrations is observed with the upgrading of the four dry-weather sewage treatment facilities (Alternative 3). A small additional improvement in BOD concentration would be obtained by implementing combined sewer overflow treatment. The natural background represents the contribution of marsh grass and other decaying vegetation and is the minimum BOD concentration obtainable by wastewater management practices. Alternative 9 yields a BOD_5 concentration that is only twice that caused by the natural background.

Referring to the spatial distribution of BOD_5 in Figures 21 and 22, the resulting spatial distribution in Jamaica Bay under the alternative wastewater management programs can be discussed qualitatively. For Alternatives 1 through 9, concentrations of BOD_5 will be higher than the average in those areas having discharges from sewage treatment facilities, those areas near any unmanaged combined sewer overflows and those areas in the center of the bay due to marsh grass decomposition. Concentrations will be lower than the average in the main channel along the north and south perimeters of the bay. For Alternatives 10 and 11, concentrations will be higher than the average near the marsh grass area and lower in all other regions except for small areas in the basins that receive significant runoff from separatly sewered areas such as Bergen Basin and Thurston Basin.

In a similar fasion the changes in the average concentration and spatial distribution of other parameters, such as HEM, total nitrogen and total phosphorus, are expected to be in proportion to the reduction or increase in pollutant loadings shown in Table 29 for each alternative wastewater management program. As a result of increasing treatment levels and increasing treatment locations, reductions in average pollutant concentrations from Alternative 1 to Alternative 9 are expected to be 30% for chemical oxygen demand, 55% for suspended solids, 53% for HEM and 8% for total phosphorus. Total nitrogen loading is expected to increase slightly to less than 2%. Relatively higher concentrations of pollutants would be observed in areas of the bay near the pollutant sources. Implementation of Alternative 10 or 11 would produce larger reductions in constituent concentrations, and the resulting values

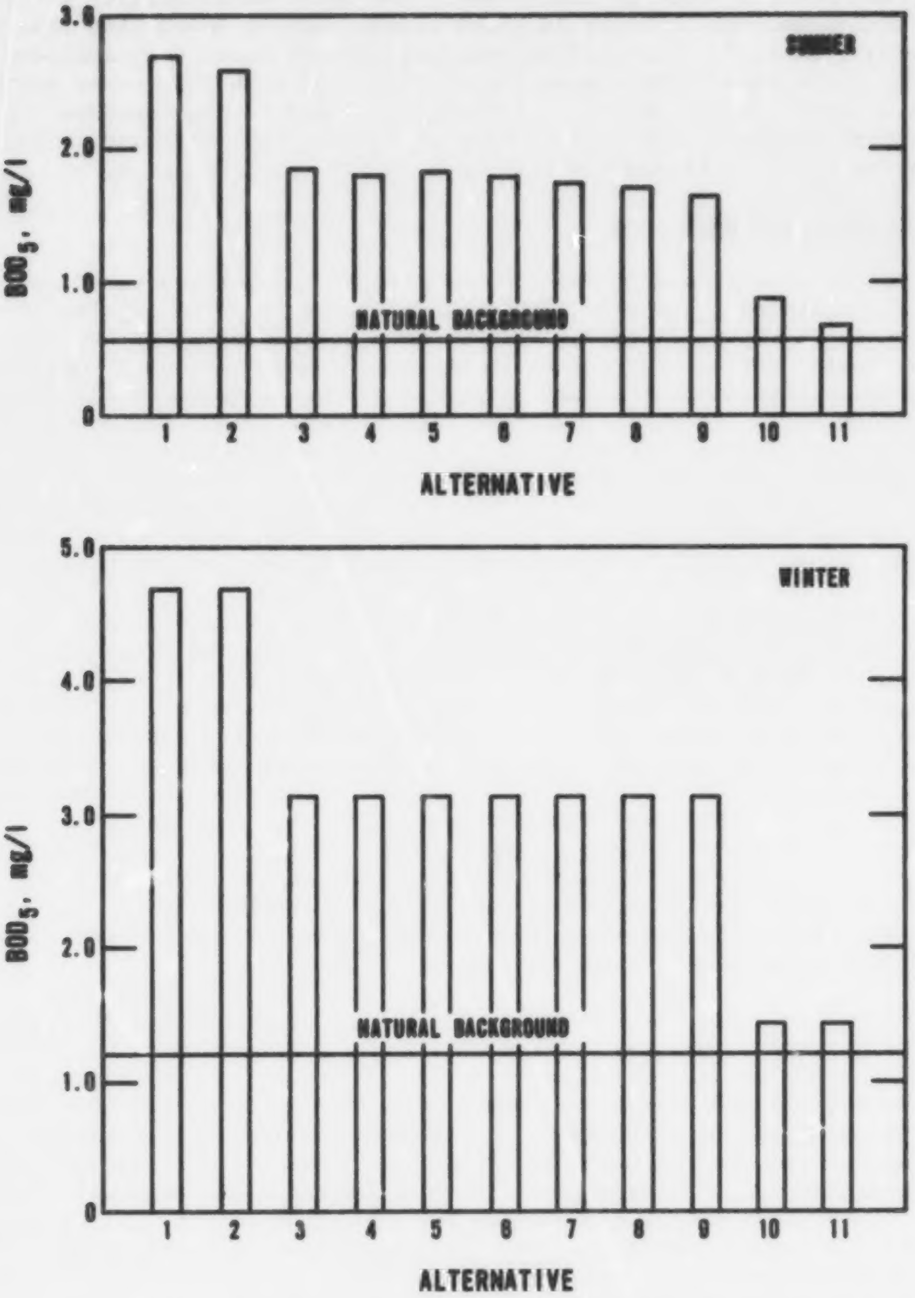

Figure 71. Effect of wastewater management programs on average BOD$_5$ concentration in Jamaica Bay

would approach background levels except in areas affected by runoff from separately sewered areas.

Costs of Alternatives

An economic analysis was performed on the 11 alternative wastewater management systems. Capital costs for upgrading the four dry-weather sewage treatment facilities and construction of the Spring Creek combined sewer overflow treatment facility were obtained from the City of New York, Department of Water Resources. The Spring Creek facility has been constructed, and construction work is proceeding on the upgrading of the 26th Ward and Rockaway facilities and enlargement of the Jamaica facility. Construction and operating costs for additional auxiliary facilities were estimated by scaling the costs of the Spring Creek auxiliary treatment facility on the basis of providing a facility capacity at each drainage basin equivalent to the overflow volume from the respective drainage basin associated with the specified design storm depth for Spring Creek. Costs of required appurtenant structures, such as interceptors and overflow structures, to route the combined sewer overflow to the auxiliary facility and thence to the bay for each drainage basin were obtained from the City of New York, Department of Water Resources.

All capital costs were amortized over a 25-yr period at a 7.0% interest rate. Construction costs were based on costs applicable to the New York area in October 1973.

Additional operation and maintenance costs, including staffing requirements, for the upgraded facilities and chlorination requirements for combined sewage overflows were estimated using the latest information available [11,12]. Operation and maintenance costs for the auxiliary facilities were estimated on the basis of actual first-year costs for the Spring Creek facility, modified to reflect the typically inflated costs associated with the start-up of a new process and facility. Sludge handling and disposal costs of $15/ton dry solids were included in the overall treatment costs and were based on current information provided by the City of New York, Department of Water Resources.

Table 31 presents the estimated costs for individual elements of wastewater management systems for Jamaica Bay. Total additional annual costs for upgrading the four sewage treatment facilities range from an estimated $2.9 million for the Jamaica facility to $6.7 million for Coney Island facility. The total annual cost for the Spring Creek auxiliary facility was $1.3 million (1973 dollars). For the other auxiliary facilities, the costs are estimated to range from $0.45 million for Hendrix Creek to $3.4 million for Thurston. The estimated total annual costs for the interceptors and outfalls, including pumping and chlorination facilities and operations, are $17.8 million for Alternative 10 and $33.6 million for Alternative 11.

Table 31. ESTIMATED ADDITIONAL COSTS FOR ELEMENTS OF ALTERNATIVE WASTEWATER MANAGEMENT SYSTEMS FOR JAMAICA BAY
(1973 dollars)

Facility	Ultimate capacity	Capital		Operation and maintenance, $1,000/yr	Total annual cost, $1,000/yr
		$1,000	$1,000/yr[a]		
WPCF					
26th Ward	85 mgd	41,087	3,700	384	4,084
Coney Island	110 mgd	74,324	6,377	475	6,852
Jamaica	100 mgd	27,737	2,380	535	2,915
Rockaway	45 mgd	42,035	3,607	764	4,371
AWPCF					
Spring Creek	1.66×10^6 ft^3	14,300	1,227	120	1,347
Fresh Creek	0.73×10^6 ft^3	9,538	819	67	886
Paerdegat	2.08×10^6 ft^3	19,562	1,679	192	1,871
Bergen	1.22×10^6 ft^3	16,782[b]	1,440	113	1,553
Hendrix	0.27×10^6 ft^3	4,991	429	25	454
Thurston	0.45×10^6 ft^3	39,007[b]	3,347	42	3,389
Rockaway	0.45×10^6 ft^3	19,092[b]	1,638	42	1,680
Outfall					
Alternative 10	1,480 mgd	196,816[b]	16,886	869	17,755
Alternative 11	7,860 mgd	370,000[b]	31,565	2,000	33,565

[a] Amortized at 7% over 25 yr.

[b] Includes interceptors.

Estimated costs of the 11 alternative wastewater management programs are presented in Table 32. It is evident that a large proportion of the total annual costs of the wastewater management alternatives are associated with the upgrading and operation of the four existing water pollution control facilities. For example, the total annual cost for upgrading the existing facilities is $18.2 million, which represents nearly 62% of the estimated total cost of upgrading the four existing facilities and providing auxiliary facilities on all combined sewer overflows to Jamaica Bay (Alternative 9).

Table 32. ESTIMATED COSTS OF ALTERNATIVE WASTEWATER MANAGEMENT PROGRAMS FOR JAMAICA BAY
(1973 dollars)

Alternative	Capital		Operation and maintenance	Total annual cost,
	$1,000	$1,000/yr	$1,000/yr	$1,000/yr
1	0	0	0	0
2	14,300	1,227	120	1,347
3	199,483	17,291	2,278	19,569
4	219,045	18,970	2,470	21,440
5	209,021	18,110	2,345	20,455
6	216,265	18,731	2,391	21,122
7	228,582	19,789	2,537	22,326
8	245,365	21,229	2,650	23,879
9	308,455	26,643	2,759	29,402
10	396,299	24,177	3,147	37,324
11	569,483	8,856	4,278	53,134

Environmental Impact

The environmental impacts include the effects of the construction of the auxiliary facilities and the changes in Jamaica Bay ecology that may result from altered discharge quantity and quality. The construction of the Spring Creek facility utilized approximately 35 ac of land, and Alternatives 4 through 9 involve even larger overall facilities that will require more land. However, many of these facilities would be built near existing water pollution control facilities and on presently unused land, mitigating to some extent their impact.

Alternatives 10 and 11 would have substantial environmental impacts due to the construction of a large interceptor outfall across the bay along Cross Bay Boulevard and the construction of two 5-mile-long ocean outfalls. Alternatives 10 and 11 would change the water circulation patterns in the bay because all of the dry-weather flow and a portion of the wet-weather flow would be diverted. This would reduce the flushing action caused by these inflows and would increase the residence time for pollutants otherwise discharged to the bay from uncontrolled sources. Alternatives 10 and 11 thus have a relatively higher environmental impact than do Alternatives 3 through 9, which involve combined sewer overflow treatment rather than routing from Jamaica Bay.

Cost-Effectiveness of Alternatives

It is an objective of this study to develop sound recommendations which maximize the benefits to Jamaica Bay for a given economic investment. Costs have been developed for each alternative, and the benefits to Jamaica Bay from each alternative have been analyzed for two parameters, total coliforms and BOD_5. Using this information, cost-effectiveness on the basis of each parameter for each of the wastewater management alternatives is shown in Figures 72 and 73. Specifically, Figures 72 and 73 depict the improvement in usable beach days and the improvement in the annual average mass discharge of BOD_5 to Jamaica Bay, respectively.

Implementation stages are shown in Figures 72 and 73 and represent alternative paths to reach a given level of usable beach days or reduced BOD_5 loading. From the perspective of maximizing usable beach days, capital investment should be on the path from Alternative 2 to Alternative 3 to Alternative 5 to Alternative 7 to Alternative 8 to Alternative 9. Implementation of Alternative 9 is the most economical means of attaining 100% usable beach days for the beaches considered. Alternative 11, which also would provide 100% usable beach days, would cost nearly twice as much as Alternative 9. From the perspective of maximizing the improvement in BOD_5 concentration, capital investment should be on the path from Alternative 2 to Alternative 3 to Alternative 11. However, an only slightly lesser reduction in BOD_5 loading could be achieved at considerably less cost ($37.3 million versus $53.1 million) upon implementation of Alternative 10. Construction of Alternative 10 would provide only 87% usable beach days. This is not significantly better than the existing conditions corresponding to Alternative 3, i.e., 81% usable beach days. Moreover, Alternatives 10 and 11 would provide average BOD_5 concentrations in summertime and wintertime that are only about 1 mg/l and less than 2 mg/l lower, respectively, than that provided by Alternatives 3 through 9.

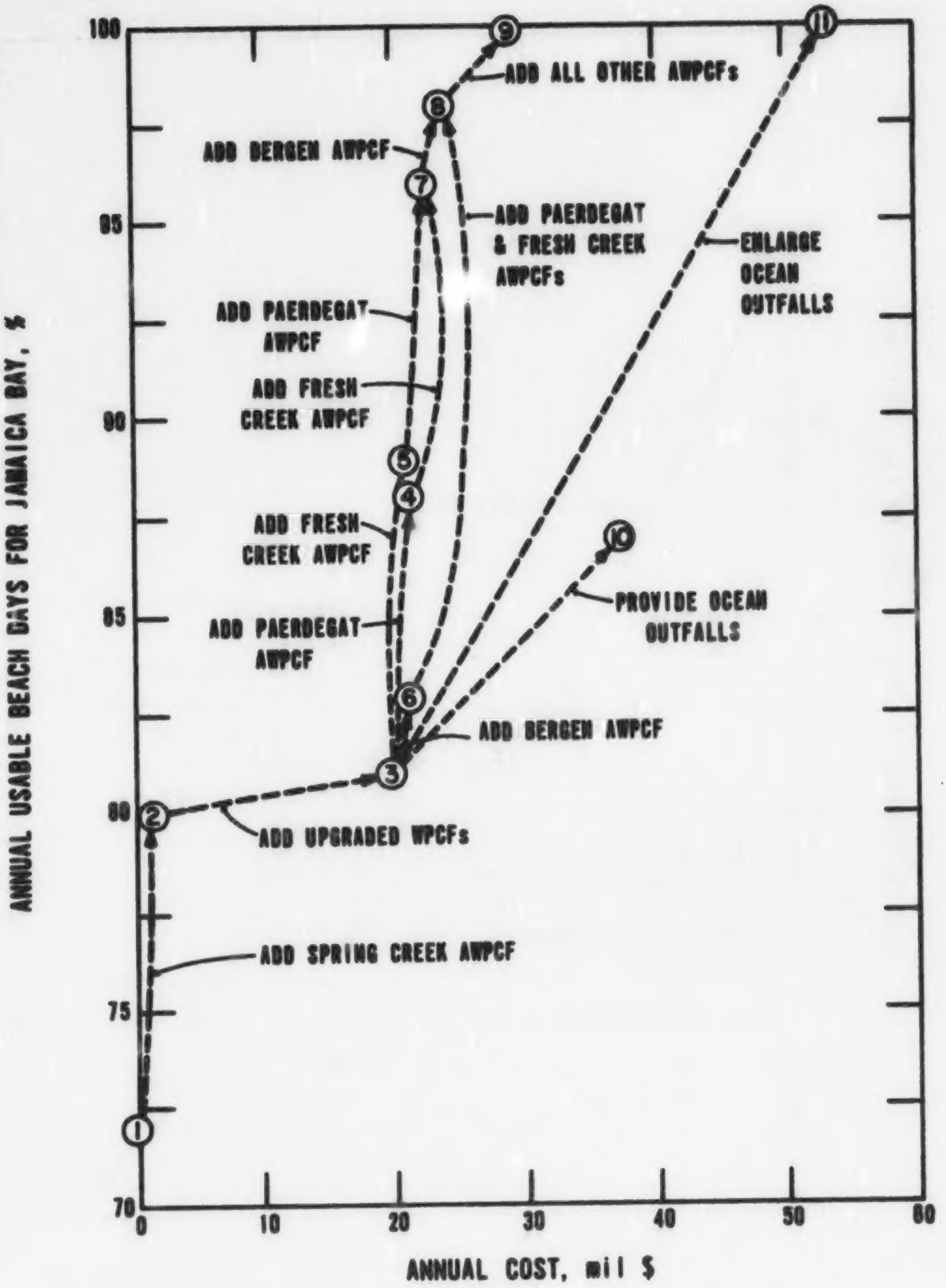

Figure 72. Cost-effectiveness (usable beach days) of alternatives

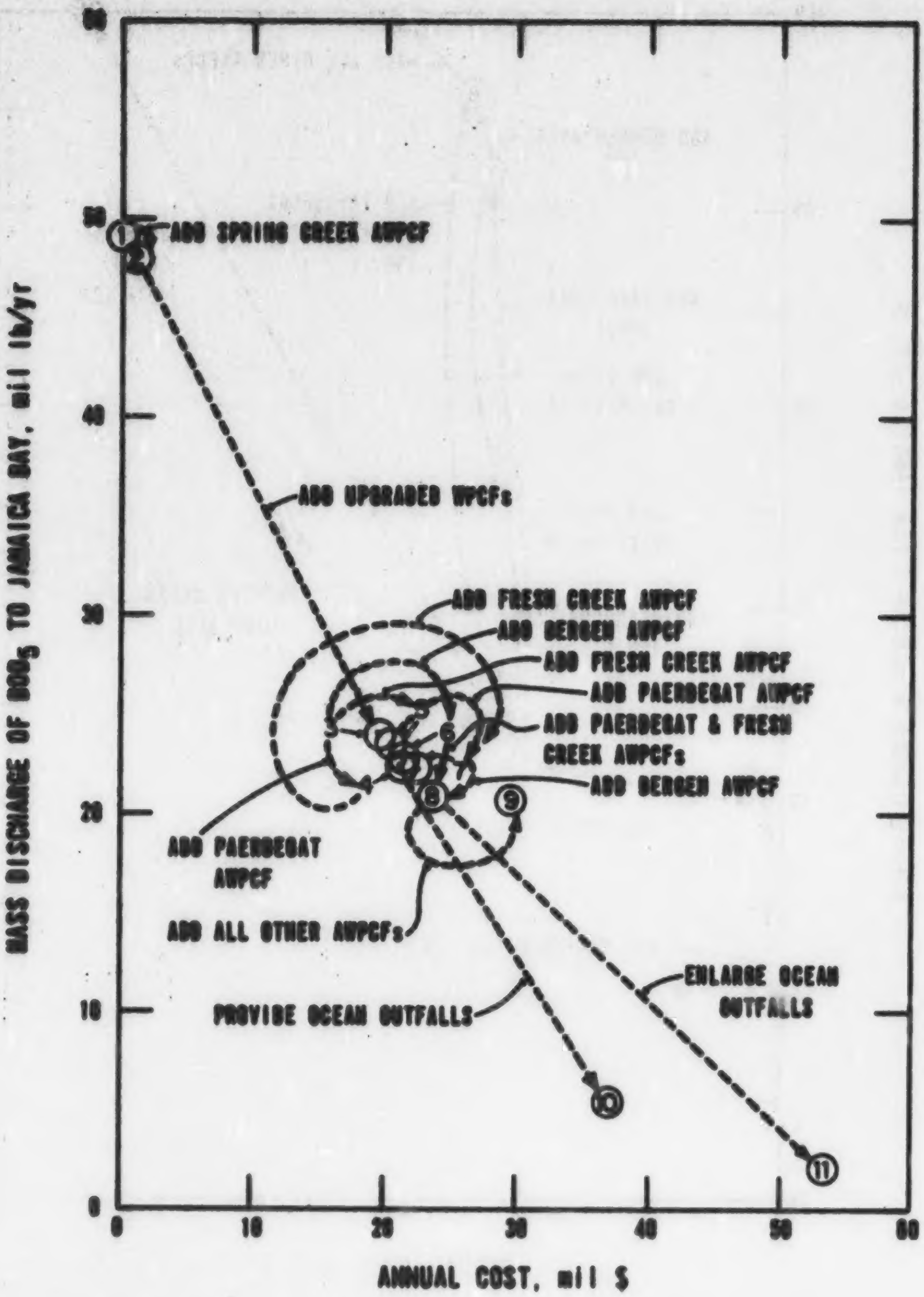

Figure 73. Cost-effectiveness (BOD) of alternatives

SECTION IX

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SECTION X

APPENDICES

APPENDIX A

BASIC DESIGN CRITERIA
SPRING CREEK AUXILIARY WATER POLLUTION CONTROL FACILITY

STORM OVERFLOWS

1. Autumn Avenue outlet from Brooklyn.

2. New Queens sewer.

RAINFALL

1. Annual average rainfall New York City, 42.37 in.

2. Annual average rainfall 5-mo summer period, 18.99 in.

3. Number of summer storms expected, 40. Number of summer storms resulting in overflows into Jamaica Bay, 20.

4. Rainfall maximum annual storm, 2.50 in.

5. Five-year storm maximum intensity, $i = 150/(t + 20)$, 2.14 in./hr.

6. One-year storm maximum intensity, $i = 75/(t + 15)$, 1.15 in./hr.

7. Intensity less than 0.50 in./hr 98% of time.

DESIGN CRITERIA

1. Tributary area, 3,256 ac.

2. Maximum rate of flow into basins, 5-yr storm, 1.38 cfs/ac or 4,490 cfs total. Detention period 6 min (infrequent occurrence).

3. Maximum rate of flow into basins, 1-yr storm, 0.75 cfs/ac or 2,440 cfs total.

4. Detention period in excess of 20 min 98% of time.

BASIN CHARACTERISTICS

Width	300 ft (six 50-ft basins)
Length	476 ft
Area	142,800 ft^2
Top elev.	6.00
Overflow weir elev.	-1.50
Av. bottom elev.	-10.60

Max. W.S. elev.	1.00
Vol. at max. W.S. elev.	1,657,000 ft^3
Av. depth at max. W.S. elev.	11.60 ft

OPERATION OF BASINS

1. Basins normally empty.

2. Basins cleaned after each storm.

3. After storm, basin contents discharged to 26th Ward Plant.

4. Approximately 63% basin volume will flow by gravity; remainder will be pumped. Gravity discharge to level of top of dam at regulator at interceptor; elevation approximately -7.0. (Arrangement also made to discharge portion of basin volume to tide through sluice gates in each basin.)

5. Cleaning operation started after basins have been dewatered.

BASIN INLET AND OUTLET

1. Connection from existing overflow to inlet chamber.

2. Inlet chamber distributes flow to basins.

3. Flow into individual basins through full height openings which may be closed by stop logs.

4. Outlet from basins over weir walls with tide gates to prevent backflow of tide.

5. Outlet weir chambers baffled by curtain walls on basin side to trap and contain froth that may develop from fall over weirs.

6. Discharge chambers to Spring Creek baffled by curtain walls to trap and contain froth that may develop from fall over weirs.

BASIN CLEANING FACILITIES

1. Deposited grit and sludge flushed by a system of spray nozzles supported on a traveling bridge (one traveling bridge cleaning mechanism provided for each basin).

2. Pressure at spray nozzle 40 psi.

3. Speed of bridge adjustable from 4 to 40 fpm.

4. Spray water supplied by pump mounted on bridge.

5. Pump takes suction from channel adjacent to each basin.

6. Suction channel intake at tidal water.

7. Entrance to suction channel provided with traveling water screen with 1/8-in. openings.

8. Trash rack with 6-in. bar spacing precedes traveling water screen.

9. Traveling bridge operation will be semi-automatic.

10. Deposited grit and sludge flushed to trough, at center of each basin, which discharges to pump wet well.

11. Maximum rate of flow of spray water is 1,000± gpm per basin, or 6,000± gpm total.

PUMPING EQUIPMENT

1. Approximately 63% of the basin volume will drain by gravity to the 26th Ward Plant.

2. Approximately 37% must be pumped.

3. Estimated capacity of the 60-in. interceptor collector to the 26th Ward Plant is 37 mgd. To maintain some reserve capacity for hourly variation of flow in the 60-in. interceptor collector, the sum of the average dry-weather flow rate and the basin dewatering flow rate should be limited to about 20 mgd when the dewatering pumps are in operation.

4. Two 2,000-gpm and two 1,000-gpm Wemco torque flow type pumps are proposed. Pumps will have variable speed fluid drives. Four pumps will dewater 37% of the basin volume in about 12 hr. Gravity dewatering of the basins and inlet sewers is estimated at about 25 hr. When the effluent sluice gates are in operation, gravity drainage time will be about 13.5 hr.

5. Two trash racks with 1-in. bar spacing, mechanically cleaned, precede pumps. Screenings removed in containers.

GRIT REMOVAL FACILITIES

1. Grit and sludge underflow from basin cleaning operation will be pumped by dewatering pumps to centrifugal-type grit separators (Dorrclones).

2. Six Dorrclones, each 24-in. diameter, capacity 1,000 gpm, proposed; total capacity 6,000 gpm.

3. Overflow from Dorrclones will be discharged to 26th Ward Plant.

4. Grit will be discharged to classifiers for washing, three 3-ton/day grit loading classifiers proposed.

5. Washed grit will be conveyed to a steel storage bin, having a capacity of 1,600 ft^3, which is about the quantity of grit expected in the maximum annual storm.

6. Grit disposal by trucks to landfills.

SOLIDS QUANTITIES

1. Screenings - estimated at 4 ft^3/mil gal.

2. Grit - estimated at 15 ft^3/mil gal.

3. Sludge - estimated quantity returned to sanitary sewer at 10% of annual average.

CHLORINATION FACILITIES

1. Mixed storm water and sanitary sewage will be disinfected during periods of storm by use of sodium hypochlorite (NaOCl).

2. Chlorine demand based on data in paper by T. R. Camp, Proceedings of Sanitary Engineering Division, ASCE, and analysis of chlorine demand sampling of combined flows obtained at the 26th Ward Plant.

3. Peak 5-yr storm flow rate 4,490 cfs or 2,900 mgd.

4. Maximum dilution ratio 130 at peak flow.

5. Four hypochlorite injectors rated at 25 gpm each.

6. Maximum design chlorine feed rate 45,000 lb/day with 3 injectors and 60,000 lb/day with 4 injectors, at 5% hypochlorite solution at maximum flow rate of 4,490 cfs. This flow is of infrequent occurrence. At flow of 2,440 cfs (peak flow, 1-yr storm), the detention period in the basins is about 10 min and the dosage will be about 4.6 ppm, with 4 injectors. Dosage rate may be increased, if required, by increasing the concentration of sodium hypochlorite solution.

7. Machines will be placed in service when water level reaches elevation -9.5 in the basins and will shut off when level in basins has receded to elevation -7.0.

8. Initial chlorine feed rate will be at a predetermined rate for a predetermined time, after which an automatic controller will operate to proportion the feed rate to the inflow rate.

9. Solution water obtained from spray water suction channels.

10. Chlorine solution will be introduced into flow by chlorine diffuser pipes located in the inlet sewers. System operates automatically as the water level rises. Three vertical diffuser pipes in each barrel of the inlet sewers will be provided.

11. Sodium hypochlorite (NaOCl) can be obtained in strengths of 5% to 15% available chlorine; a 15% solution contains 1.25 lb of available chlorine/gal. The solution will be fed automatically through hypochlorinators to the diffusers; 12,000 lb of available chlorine will provide chlorination for a major storm, with reserve capacity for two additional average storms or for a second major storm; 12,000 lb is equivalent to 10,000 gal. of 15% concentration, or 30,000 gal. at 5%

concentration. Provisions made for two 15,000-gal. storage tanks which allows for dilution to 5% concentration to reduce rate of deterioration.

METERS

1. Meters will be provided to measure the rate of storm water inflow to the basins and the chlorine application rate. The meters will be of the magnetic flow type. Basin outflow will be determined by measurement of heads upstream and downstream of the effluent weir and the rates calculated from the head measurements.

2. A chlorine residual recorder, receiving sample from the basin overflow, will be provided.

3. Supervisory alarm systems will be provided to transmit alarms to the 26th Ward Plant.

VENTILATION

1. Pumping station will be ventilated by a system of fresh air intakes and exhaust fans in roof, complete with duct systems.

2. The basins proper will be ventilated by a system of fresh air inlet fans and exhaust fans. Fresh air is drawn in at south end through fixed louvres and gravity shutters and discharged through exhaust fans located at the north end.

3. The ventilation system is designed to allow for the future addition of an odor control system, if required.

ELECTRICAL SYSTEM

1. Power supplied by Con Edison at 460 volts, 3 phase, 60 cycles. Distribution centers provided for power and light.

STRUCTURAL FEATURES

1. The structures are essentially of reinforced concrete with structural steel framing for the pumping station. The basins are covered and are entirely of reinforced concrete.

ARCHITECTURAL FEATURES

1. The pumping station and basins are of simple modern design. Exterior essentially consists of pre-cast, exposed aggregate, concrete panels.

APPENDIX B

POLLUTANT MASS EMISSION FROM COMBINED SEWER AREAS

Several parametric relationships were constructed and evaluated in order to develop a general predictive correlation between mass emission rate of each pollutant and overflow volume (expressed as depth) from combined sewer overflows.

Good correlations were obtained when the areal intensity of pollutant mass emission, expressed in pounds per acre (lb/ac), of drainage area was related to overflow volume, expressed in inches (in.) of overflow occurring from the drainage area. Straight-line relationships between these parameters were obtained for each pollutant studied. The relationships are presented in Figures 74 through 80 for BOD_5, chemical oxygen demand, suspended solids, HEM, total organic nitrogen, total inorganic nitrogen and total soluble phosphorus, respectively. Detailed data are presented in Table 33.

The relationships appear to be independent of specific drainage basin characteristics and thus provide a general method for determining the pollutant mass emission rates from combined sewer overflows from urbanized areas similar to those tributary to Jamaica Bay.

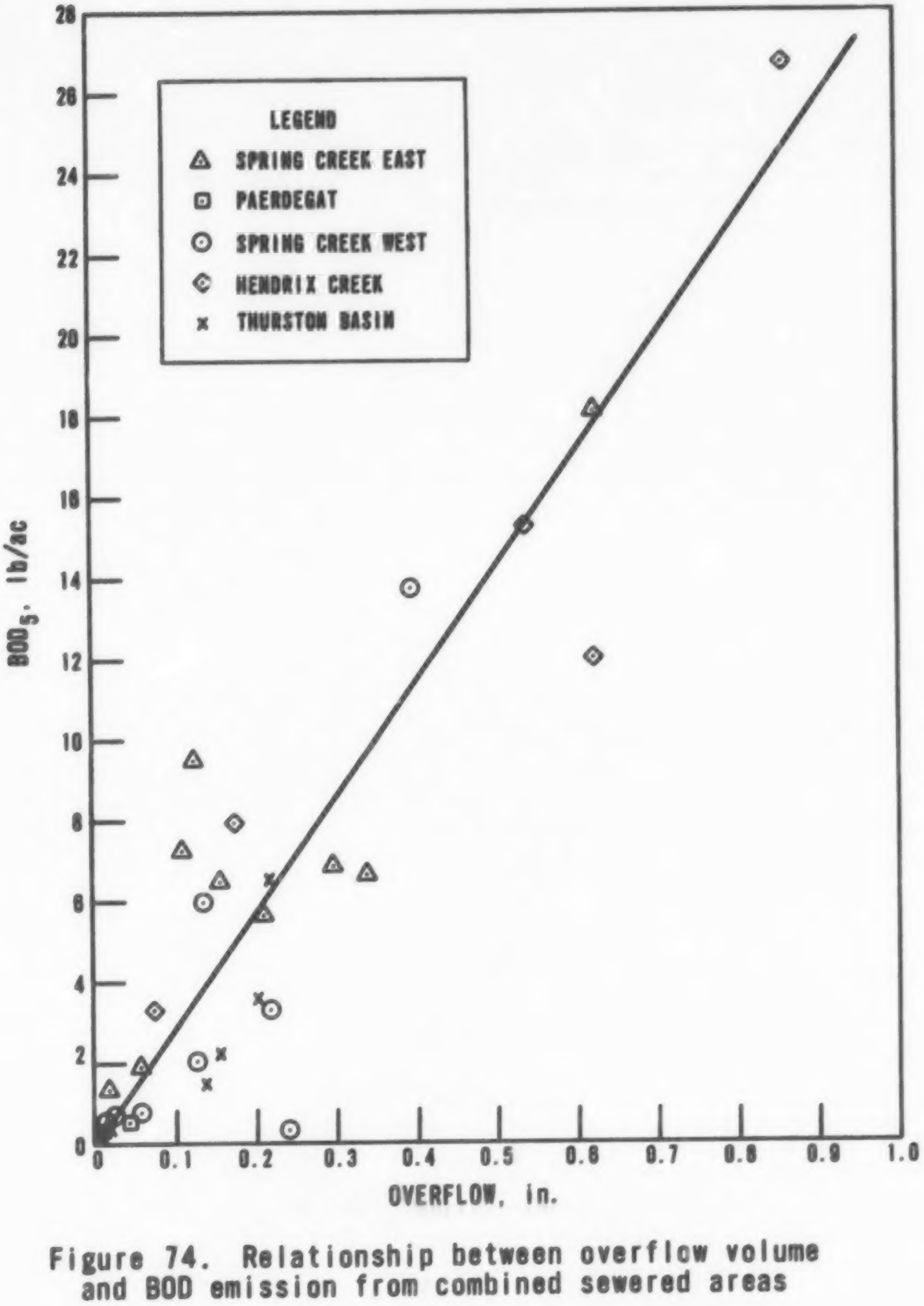


Figure 74. Relationship between overflow volume and BOD emission from combined sewered areas

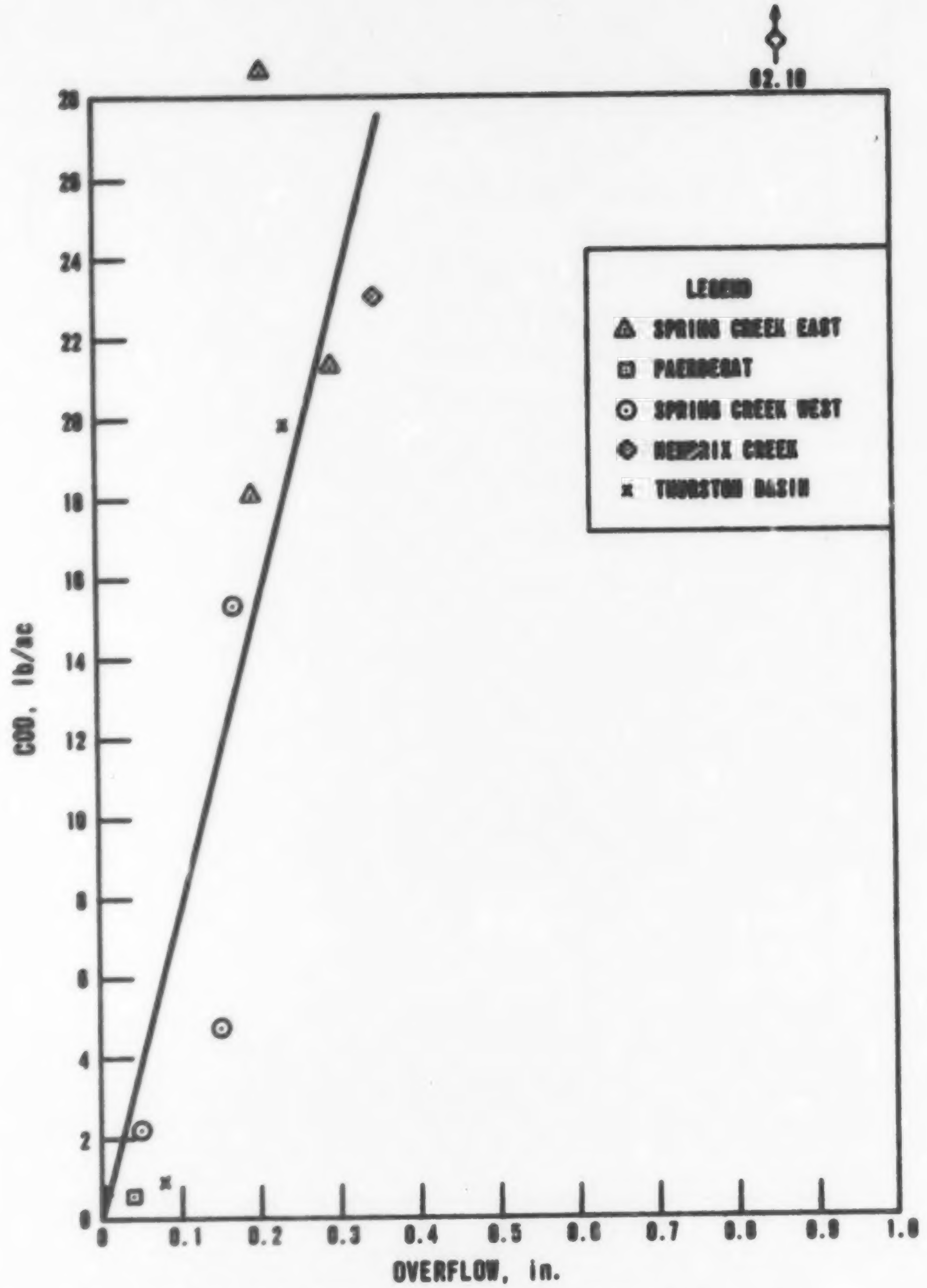


Figure 75. Relationship between overflow volume and COD emissions from combined sewered areas

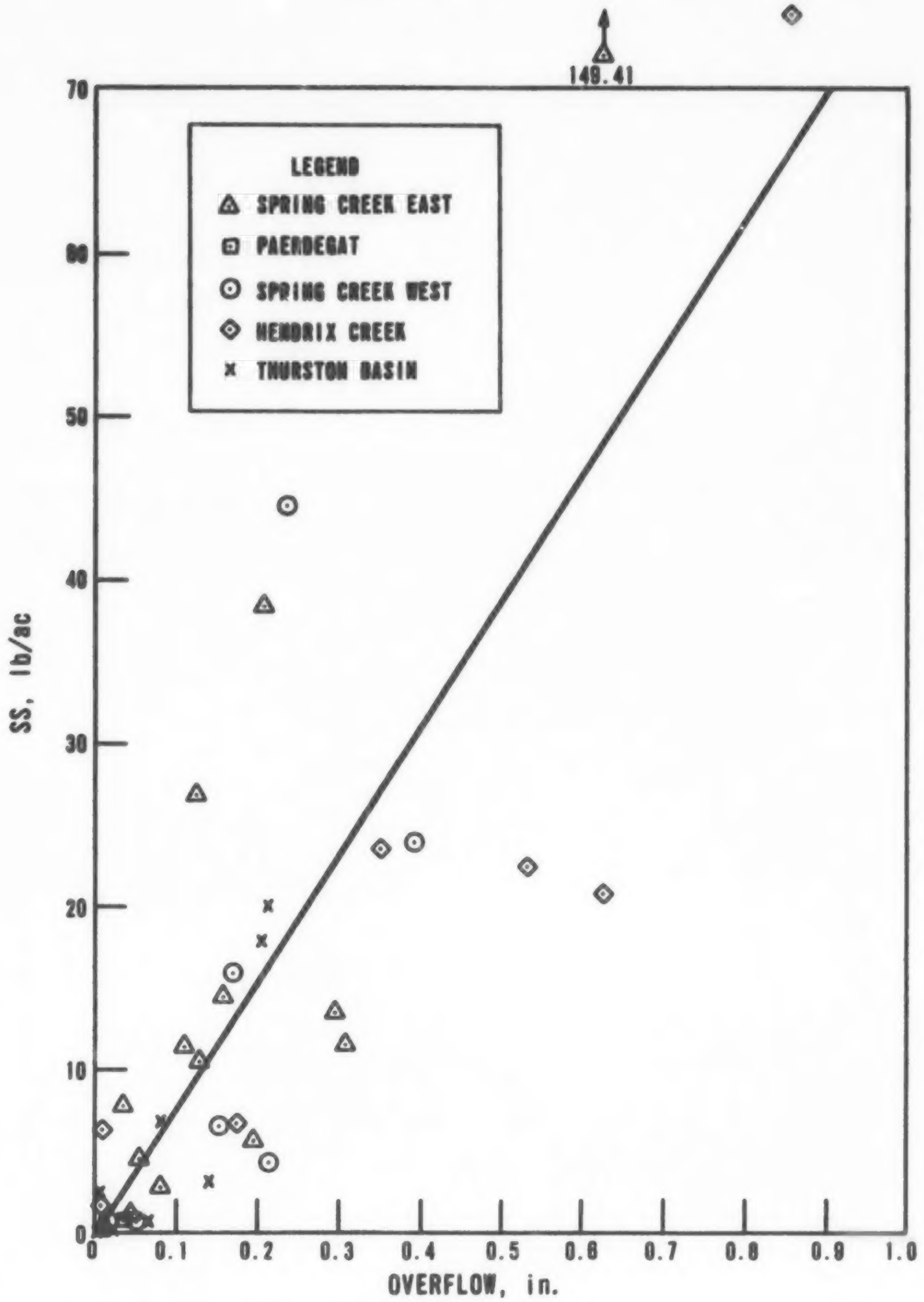


Figure 76. Relationship between overflow volume and suspended solids emissions from combined sewered areas

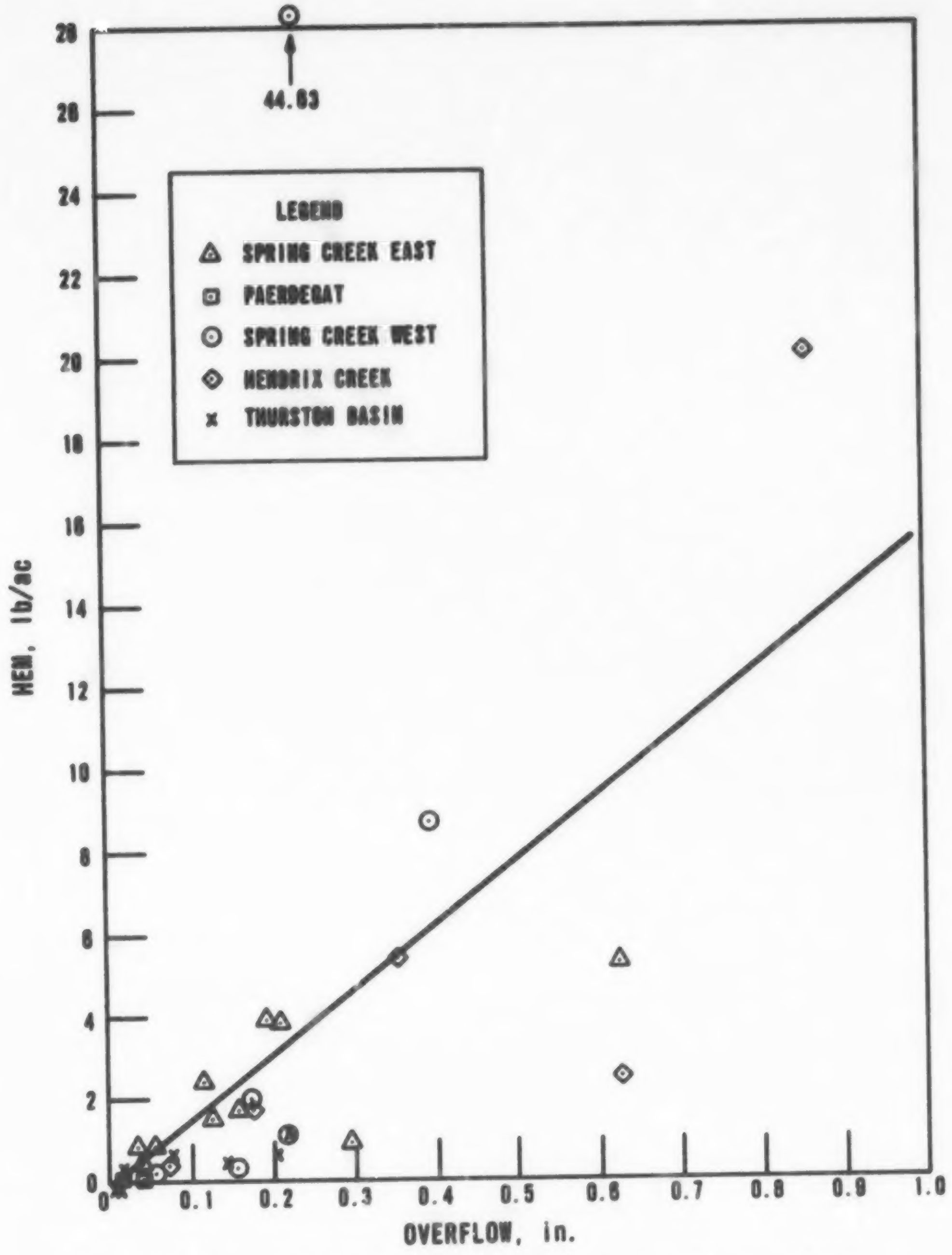


Figure 77. Relationship between overflow volume and HEM emission from combined sewered areas

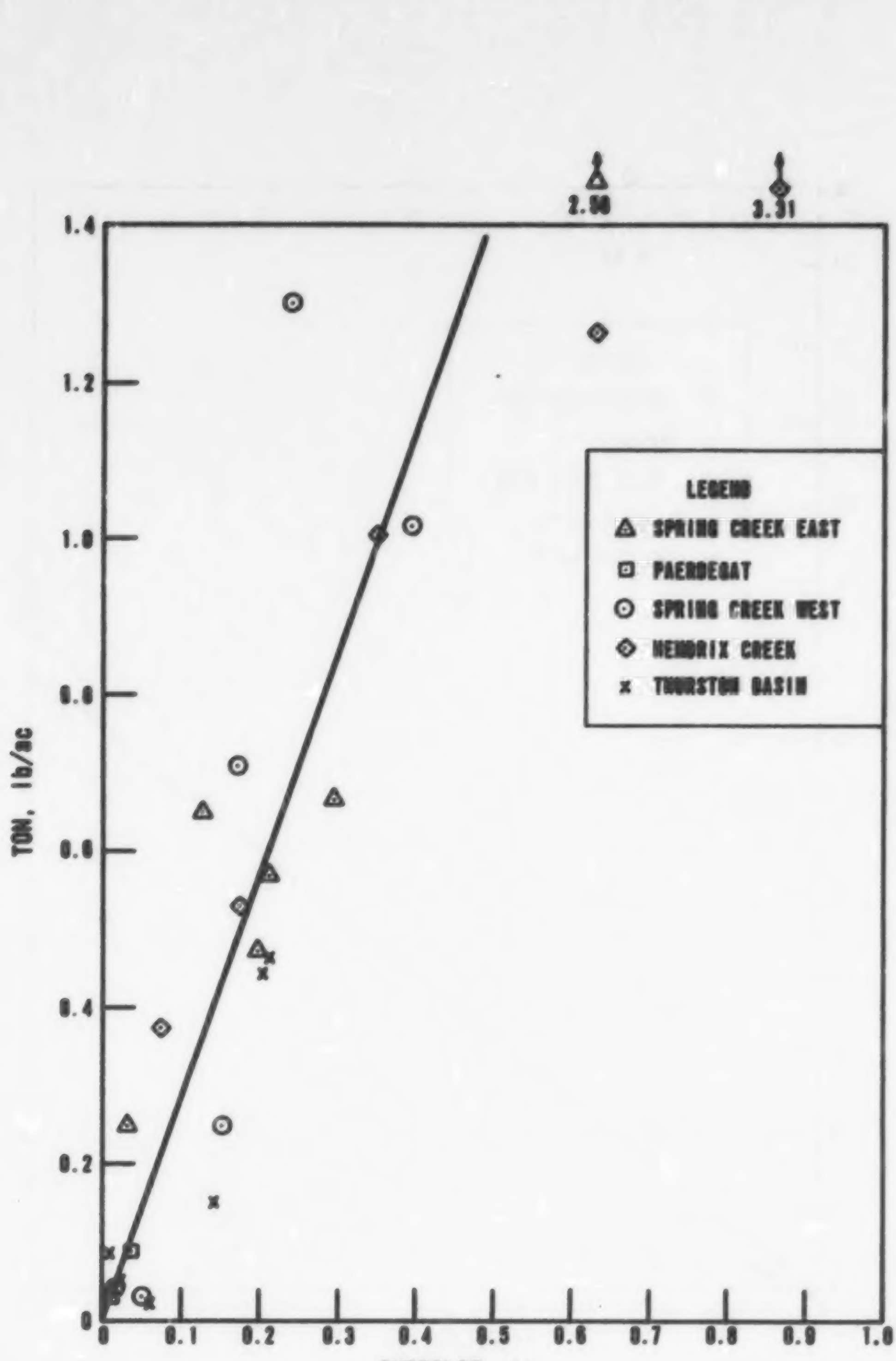


Figure 78. Relationship between overflow volume and total organic nitrogen emission from combined sewered areas

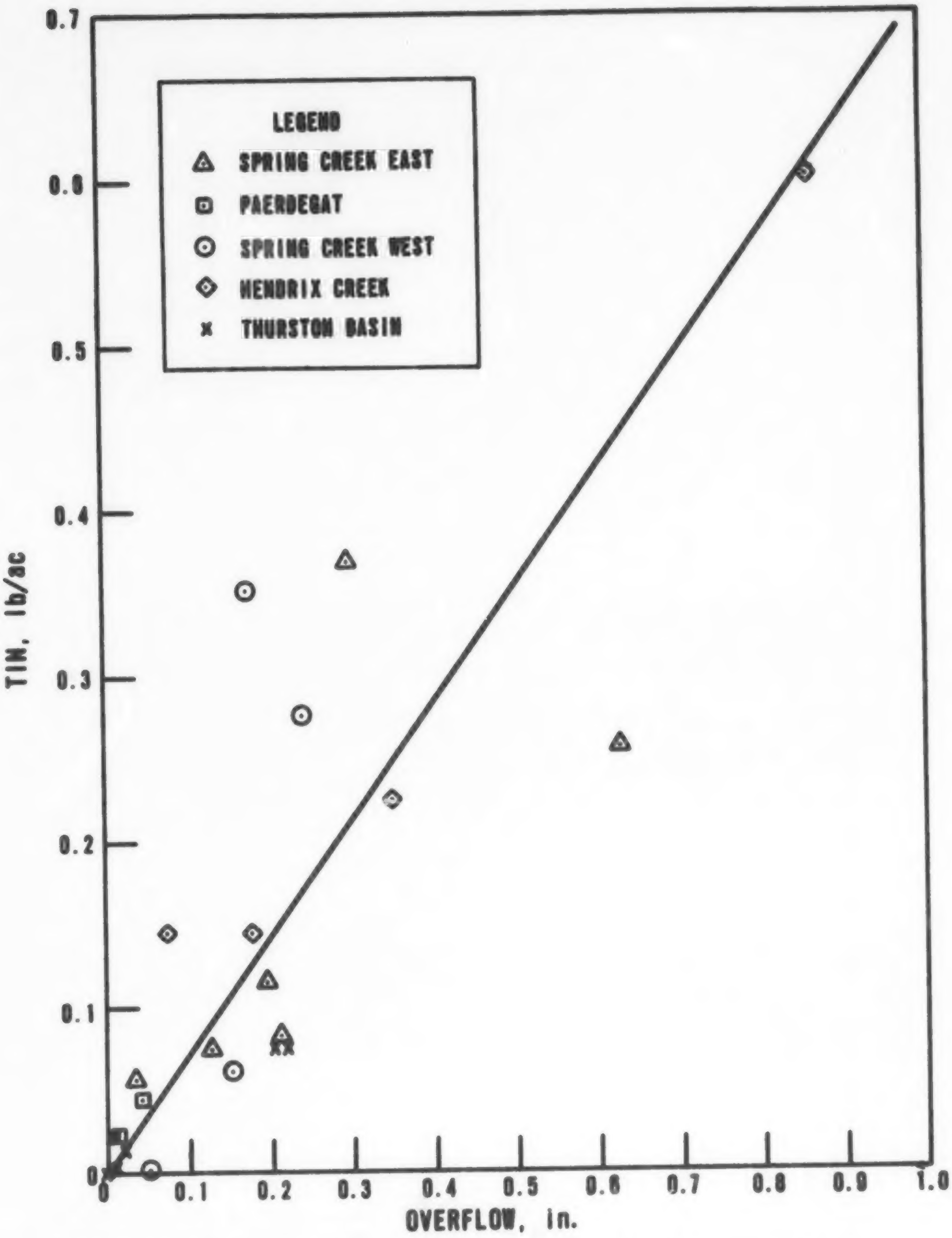


Figure 79. Relationship between overflow volume and total inorganic nitrogen emission from combined sewered areas

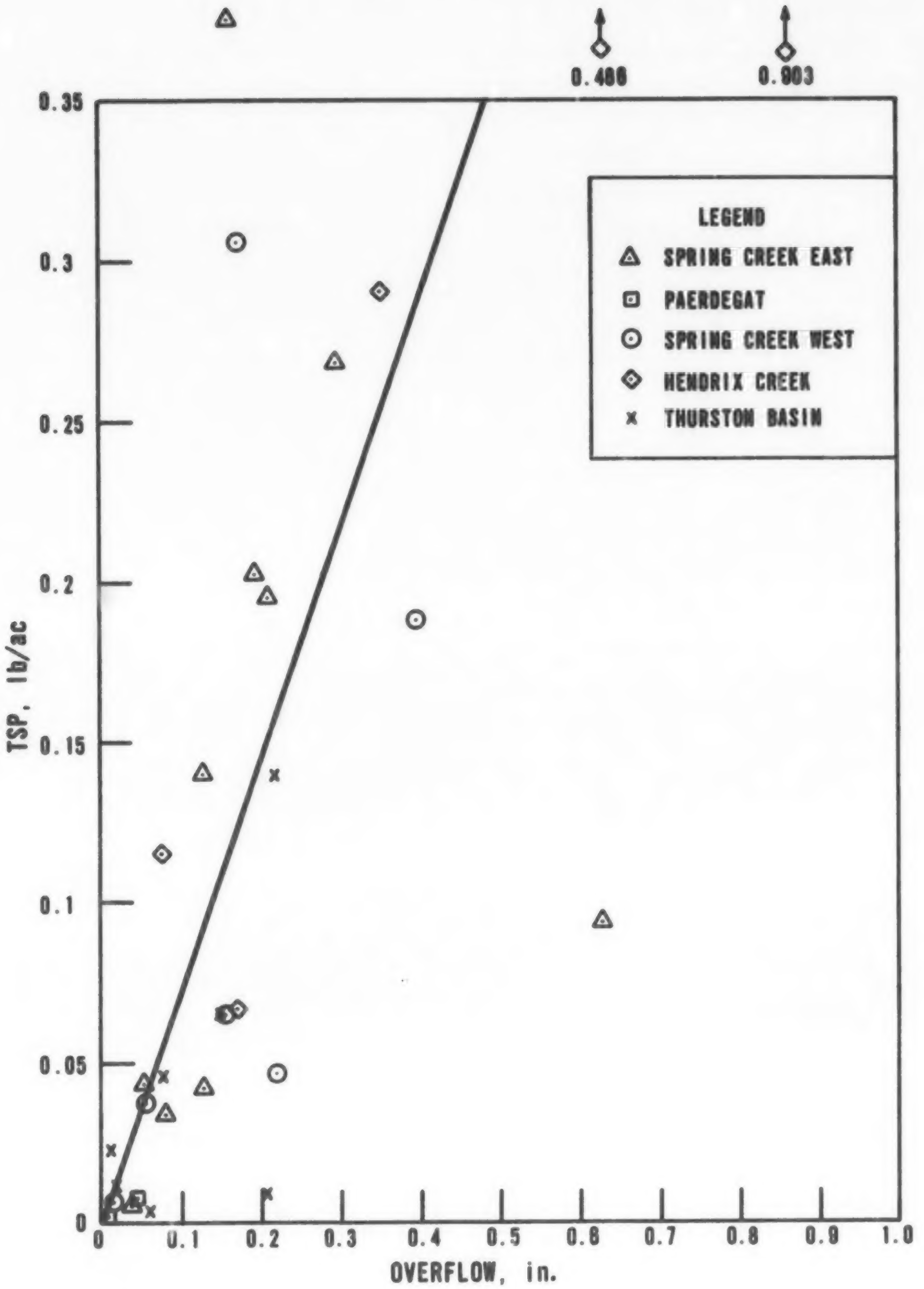


Figure 80. Relationship between overflow volume and total soluble phosphorus emission from combined sewered areas

Table 33. CUMULATIVE MASS EMISSION AND COMBINED SEWER OVERFLOW DATA, JAMAICA BAY

Basin	Date of storm	Overflow volume, in.	Mass emission, lb/ac						
			BOD_5	COD	SS	HEM	TON	TIN	TSP
Spring Creek East									
N-1	22 Apr 69	0.303	-	-	11.5	-	-	-	-
N-2	9 May 69	0.296	6.88	21.4	13.3	0.971	0.674	0.370	0.269
N-3	3 Jul 69	0.210	5.64	28.7	38.2	3.85	0.567	0.074	0.195
N-4	10 Jul 69	0.196	-	18.1	5.83	3.91	0.487	0.114	0.202
N-5	12 Jul 69	0.042	-	-	1.36	-	-	-	-
N-6	4 Mar 70	0.124	-	-	10.5	1.46	-	-	0.140
N-7	20 Mar 70	0.080	-	-	2.84	0.443	-	-	0.034
N-8	23 Mar 70	0.056	1.94	-	4.63	0.858	-	-	0.043
N-9	26 Mar 70	0.159	6.52	-	14.4	1.71	-	-	0.378
N-10	2 Apr 70	0.375	6.60	-	-	-	-	-	-
N-11	20 Apr 70	0.108	7.30	-	11.5	-	-	-	-
N-12	27 Sep 70	0.124	9.52	-	26.9	2.51	0.653	0.073	0.042
N-13	3 Oct 70	0.036	1.30	-	7.80	0.819	0.251	0.056	0.005
N-14	15 Oct 70	0.625	18.2	-	149	5.26	2.58	0.256	0.094
Paerdegat									
P-1	18 Jun 70	0.040	0.488	-	0.805	0.087	0.824	0.044	0.007
P-2	10 Jul 70	0.012	0.417	-	0.417	0.125	0.356	0.021	0.002
P-3	31 Jul 70	0.039	-	-	-	-	-	-	-

Table 33 (Continued). CUMULATIVE MASS EMISSION AND COMBINED SEWER OVERFLOW DATA, JAMAICA BAY

Basin	Date of storm	Overflow volume, in.	Mass emission, lb/ac						
			BOD$_5$	COD	SS	HEM	TON	TIN	TSP
Spring Creek West									
S-1	3 Jul 69	0.173	6.00	15.3	15.9	1.99	0.709	0.351	0.306
S-2	17 Jul 69	0.054	0.645	2.28	0.626	0.152	0.014	0.009	0.036
S-3	29 Jul 69	0.154	2.05	4.77	6.61	0.320	0.249	0.052	0.065
S-4	22 Dec 69	0.014	0.423	-	0.705	-	0.041	-	0.005
S-5	2 Apr 70	0.218	3.31	-	4.10	1.02	-	-	0.046
S-6	24 Apr 70	0.024	0.618	-	-	-	-	-	-
S-7	15 Oct 70	0.393	13.9	-	24.0	8.69	1.08	-	0.189
S-8	26 Jan 71	0.240	0.372	-	44.6	46.7	1.30	0.276	-
Hendrix Creek									
H-1	24 Mar 69	0.860	26.7	82.1	74.9	20.0	3.31	0.602	0.903
H-2	10 Jul 69	0.351	-	23.1	23.7	5.40	1.05	0.225	0.291
H-3	29 Sep 69	0.093	-	-	6.41	-	-	-	-
H-4	21 Oct 69	0.074	3.29	-	1.81	0.379	0.377	0.148	0.115
H-5	4 Nov 69	0.623	12.0	-	20.8	2.54	1.26	-	0.486
H-6	2 Feb 70	0.537	15.3	-	22.3	-	-	-	-
H-7	4 Nov 70	0.175	7.91	-	6.80	1.63	0.530	0.145	0.067
Thurston									
T-1	3 Jul 69	0.218	6.53	19.9	20.2	1.15	0.464	0.076	0.140
T-2	10 Jul 69	0.020	-	-	0.463	0.208	0.045	0.013	0.010

Table 33 (Continued). CUMULATIVE MASS EMISSION AND COMBINED SEWER OVERFLOW DATA, JAMAICA BAY

Basin	Date of storm	Overflow volume, in.	Mass emission, lb/ac						
			BOD5	COD	SS	HEM	TON	TIN	TSP
T-3	12 Jul 69	0.063	-	-	0.798	-	-	-	-
T-4	17 Jul 69	0.011	0.404	0.728	2.49	0.090	0.084	0.024	0.024
T-5	26 Aug 69	0.079	-	0.974	6.99	0.438	-	-	0.047
T-6	7 Sep 69	0.001	-	-	0.019	-	-	-	-
T-7	21 Oct 69	0.012	0.378	-	0.965	0.079	0.051	0.006	0.007
T-8	4 Nov 69	0.141	1.52	-	3.17	0.448	0.158	-	0.065
T-9	8 Dec 69	0.153	2.33	-	6.33	-	-	-	-
T-10	10 Dec 69	1.032	-	-	41.2	-	-	-	-
T-11	3 Oct 70	0.006	0.192	-	0.495	0.062	0.025	0.005	0.002
T-12	15 Oct 70	0.205	3.69	-	18.1	0.722	0.453	0.074	0.008

APPENDIX C

MATHEMATICAL MODELS

RECEIVING WATER MODEL FOR COLIFORM DENSITY

A mathematical model was developed to enable prediction of the coliform density at a given beach following a given storm size. This was then used to determine the percentage of time that a given beach would be usable, i.e., would meet the receiving water coliform standard under a particular wastewater management alternative.

Input for the Coliform Model

Input for the coliform model includes data describing the storm characteristics, the quantity and quality of the resulting combined sewer overflow from each drainage basin, the quantity and quality of runoff from separately sewered areas, the quantity and quality of dry-weather sewage treatment facility effluents, the tidal conditions at the time of the storm, the bay dilution and circulation and the coliform disappearance rate. The basin characteristics and water pollution control facility dry-weather flow discharge quantity and quality were presented in Sections IV and VII; the remaining input is discussed in the following paragraphs.

Coliform Loadings--

The receiving water coliform model utilized data generated by the urban runoff models for the total coliform loading to the bay from each drainage basin as a function of total storm depth [10]. The relations developed are shown in Figure 65. As output was not available for Paerdegat and Fresh Creek Basins, total coliform concentrations were determined from the drainage area, appropriate overflow coefficients and assumed average coliform concentrations of 156,000 MPN/ml for Paerdegat Basin and 650,000 MPN/ml for Fresh Creek Basin.

The coliform loading from separately sewered areas for different storm sizes was computed using the drainage area, a runoff coefficient of 0.65 and, based upon the Rand model [9], an average coliform concentration of 9,000 MPN/ml. The contribution of urban runoff is small compared to untreated combined sewer overflows.

Circulation in Jamaica Bay--

Water circulation in Jamaica Bay is important in determining the pollutant distribution from combined sewer overflows. The influence of a particular combined sewer overflow at one or more beach sites is dependent upon the tidal excursion, which is the distance travelled during the flooding or ebbing tide stage. Water movement in the bay is generally back and forth with the tidal currents and will slowly leave the bay at the net advective flow. However, if a beach site is not within the range of a combined sewer overflow discharge on the first or second tidal cycle, the coliforms may disappear to a negligible level before they will arrive at the beach at the net advective velocity. The net flow in Jamaica Bay is very small, in the order of 0.003 to 0.15 fps. Tidal current charts [13] were used to estimate the current direction and velocity at each station in Jamaica Bay for every hour of the 12-hr tidal cycle. Typically, the currents fluctuate between 2 fps into the bay and 2 fps out of the bay except in the Grassy Bay area, where the maximum currents are in the order of 0.5 fps.

Further information on the volume available for dilution was obtained from the U.S. Coast and Geodetic Survey Nautical Chart 542-SC.

Coliform Disappearance Rate--

Coliform disappearance studies were conducted during the course of the project to determine the rate of decay in the receiving water environment. As a result of these studies, it was found that 90% of the coliforms disappeared within 24 hr (T_{90} = 24 hr), providing a rate constant of 0.10 day^{-1}.

Computational Procedures for the Coliform Model

In tracking the fate of a combined sewer overflow of known coliform loading to Jamaica Bay, it is first important to calculate the dilution and coliform disappearance that occurs in the side channel or basin and then the dilution and coliform disappearance during transport in the main channel to a nearby beach.

The reaction in the basin can be represented by

$$C_1 = C_0 e^{-k_1 t} \tag{4}$$

where C_1 = concentration of coliforms after time t, MPN/ml;

C_0 = initial concentration = $\dfrac{\text{total storm loading, MPN}}{\text{basin volume, ml}}$;

$k_1 = 2.67 \times 10^{-5}\ \text{sec}^{-1}$ (0.10 day^{-1}); and

t = residence time in basin, sec.

Assuming that an average summer overflow lasts 2 hr and that the storm starts at low water or at high water, the normal residence time is 4 hr. A delay of 16 hr for Paerdegat Basin was used because of its extensive length.

Because of the geometry of the basin-main channel network, it can not be assumed that the discharge from the basin is instantaneously mixed across the main channel cross-section. Some initial mixing will occur followed by a lateral spreading across the channel. An analysis similar to ocean outfall analysis can be made. The initial mixing is taken as

$$C_2 = \frac{QC_1}{Vbh} \tag{5}$$

where C_2 = concentration of coliforms prior to lateral dispersion, MPN/ml;

Q = average flow rate out of the basin on ebb tide = tidal prism/6 hr, ft^3/sec;

V = average velocity in main channel, fps;

b = width of basin, ft; and

h = average depth of main channel at junction, ft.

The phenomena of lateral spreading and disappearance during transport to a beach can be obtained from the following equation [14]:

$$C_3 = C_2 e^{-k_1 t} \text{ erf } \left[\frac{b}{4} \sqrt{\frac{1}{E_y t}} \right] \tag{2}$$

where C_3 = concentration of coliforms after lateral dispersion of time t, MPN/ml;

$k_1 = 2.67 \times 10^{-5}\ sec^{-1}$;

t = travel time to beach $\leq$ 6 hr, sec;

b = initial width of combined sewer outfall field in main channel = width of basin, ft; and

E_y = coefficient of lateral diffusion, ft^2/sec.

On the basis of available information [9], E_y was assumed to be 4% of the coefficient of longitudinal diffusion. These latter coefficients were computed on the basis of salinity distributions obtained during this project.

The cumulative effects of all combined sewer overflow discharges at a particular beach were taken as the sum of all discharges having a travel time of less than 6 hr. The flood tide and the ebb tide were considered separately. The travel times are shown on Table 34. The effect of Paerdegat Basin was handled by computing the cumulative effect at each beach without Paerdegat on the first tidal cycle and then adding the effects of Paerdegat on the second tidal cycle, with the first tidal cycle contribution decayed at the rate of 90%/24 hr to reflect coliform disappearance. The highest concentration at each beach was used for evaluation purposes.

Table 34. ARRIVAL TIME IN HOURS FROM BEGINNING OF TIDAL CYCLE

Discharge	Beach 1		Beach 2		Beach 3		Beach 4	
	Flood	Ebb	Flood	Ebb	Flood	Ebb	Flood	Ebb
Coney Island WPCF	3.11	-	7.24	-	>>8	-	>>8	-
Mill Basin	-	0.37	2.7		5.11	-	9.04	-
Paerdegat Basin	-	2.28	0.48		2.89	-	6.92	-
Fresh Creek	-	4.32	-	2.18	-	0.61	3.16	-
Hendrix Creek	-	5.07	-	2.93	-	1.36	3.98	-
Spring Creek	-	6.72	-	4.58	-	3.01	1.74	-
Bergen Basin	-	8.97	-	6.83	-	5.26		1.09
Jamaica WPCF	-	>>8	-	>>8	-	8.35		4.18

The computations were made for each of the four most promising potential beach sites for storm sizes (depths) of 0.10, 0.50 and 1.0 in. Corresponding coliform loadings from each basin were obtained from Figure 65. Treatment plants were assumed to discharge at their rated capacity during the 6-hr residence time in the basin. The procedure was followed first assuming that the beginning of the storm was coincident with low water and then separately with the storm coincident with high water.

It is desirable to express the results of the analysis in terms of the percentage of time during the summer months that a given beach would be usable, i.e., that water quality is sufficiently high to allow water contact sports. A frequency distribution of the number of storms occurring during the summer season (1 May to 30 September) [10] indicated that during an average summer there were 5 storms larger than 1.0-in. depth, 8 storms having a depth between 0.1 and 0.5 in. and 10 storms having a depth less than 0.1 in. The maximum concentration at each beach for each storm size in the above categories occurring on an ebbing tide and on a flooding tide were computed. Then, using a coliform disappearance rate of 0.10 day^{-1}, the lengths of time that the water quality standards would be exceeded from such a storm were determined for each beach. Results for ebbing tide and flooding tide were averaged and multiplied by the number of storms in each storm-size category and the total from all categories obtained to give the total number of unusable beach days during the summer season. The percentage of usable beach time at each beach was then determined given that there are 153 possible usable days in the 1 May to 30 September period.

Coliform Model Verification

It is important to verify the accuracy of the coliform model before it is used as an evaluative tool for combined sewer overflow management alternatives. The Rand model has been used [9] to simulate the behavior of Jamaica Bay responding to storms of 0.75 and 1.08 in. at different tidal conditions. Assuming that this model accurately represents bay behavior (it has since been verified with actual data), these results can be compared with the Engineering-Science coliform model developed in this project. A comparison is made in Table 35, which shows that the Engineering-Science model predicts maximum coliform concentrations which agree reasonably well with those of the Rand model. The discrepancies are not large considering the difference that can be caused by slight changes in storm duration and tidal conditions and by the more accurate modeling of the basin response. Also, the Engineering-Science model ignores the Pumpkin Patch Channel, which will reduce concentrations at Beach 4 and add them to Beach 1 on ebbing tide and vice versa on flooding tide.

Table 35. PREDICTED MAXIMUM COLIFORM CONCENTRATIONS[a]

	ES model		Rand model	
Beach	MPN/ml	Unusable beach days	MPN/ml	Unusable beach days
0.75-in. storm at low tide				
1	200	1.0	120	1.2
2	2,000	2.0	1,000	1.9
3	5,000	2.3	1,500	2.2
4	70	.5	400	2.3
1.08-in. storm at high tide				
1	2	0	60	1.0
2	1,200	1.7	1,200	2.3
3	1,300	1.8	2,500	2.3
4	90,000	3.6	8,000	2.8

[a] No combined sewer overflow treatment facilities in operation (Atlernative 1).

Unusable beach days corresponding to coliform concentrations predicted by the Engineering-Science model were determined by assuming that the maximum concentration will decay 90% every 24 hr. Unusable beach days from the Rand model output were determined by the length of time coliform concentration was above the water quality standard of 24 MPN/ml. In both models it was assumed that background concentration of coliforms was 10 MPN/ml. The comparative agreement between the two models in terms of unusable beach days associated with these two storms is closer than the actual concentration values and is considered adequate for the expressed purposes of the Engineering-Science coliform model.

RECEIVING WATER MODEL FOR BOD

Sources of BOD

The mass discharges of BOD_5 to Jamaica Bay are tablulated in Table 36 for various wastewater management alternatives.

Table 36. AVERAGE ANNUAL BOD_5 LOADINGS TO JAMAICA BAY (mil lb/yr)

Treatment alternative	Treatment plants	Combined sewer overflows	Combined storm sewer runoff	Other sources	Total
Prior to WPCFs[a] upgrading	32	7	2	0.02	41.0
Prior to WPCFs upgrading and SCAWPCF[b]	32	6	2	0.02	40.0
Upgraded WPCFs and SCAWPCF	16	6	2	0.02	24.0
Upgraded WPCFs and AWPCFs[c] on all combined sewer overflows	16	3	2	0.02	21.0

[a] Water pollution control facilities (dry-weather sewage treatment).

[b] Spring Creek Auxiliary Water Pollution Control Facility (combined sewer overflow treatment).

[c] Auxiliary water pollution control facilities (combined sewer overflow treatment).

Steady-State Model

A model was developed to show the improvement in the seasonal receiving water BOD_5 concentration under different combined sewer overflow management alternatives. The general approach of the BOD model is to compute resulting concentrations on the basis of a seasonal mass balance of sources and sinks. The one-dimensional equation for constituent concentration, C, for a variable area, unsteady input/output situation is:

$$\frac{\partial (AC)}{\partial t} = \frac{\partial (AE\frac{\partial C}{\partial x})}{\partial x} + \frac{\partial (A\bar{u}C)}{\partial x} - kC \qquad (6)$$

where A = cross-sectional area at distance x;

t = travel time to x;

E = longitudinal diffusivity;

$\bar{u}$ = average cross-sectional velocity at x; and

k = constituent rate of decay.

At steady-state, the above expression for BOD may be written:

$$E\frac{d^2L}{dx^2} - \bar{u}\frac{dL}{dx} - (k_2 + k_3)L + R_a = 0 \qquad (7)$$

where L = ultimate BOD of the receiving water;

k_2 = BOD exertion rate constant;

k_3 = BOD removal by sedimentation, etc.; and

R_a = rate of BOD_5 addition.

When computing the average concentrations within the bay, d^2L/dx^2 and dL/dx are zero, and the mass balance equation simplifies to:

$$(k_2 + k_3)L = R_a \qquad (3)$$

Because k_2 is a function of temperature, the following equation was used to adjust the value to another temperature, T:

$$K_{2_T} = k_{2_{20}}(1.040)^{(T-20)} \qquad (8)$$

where $k_{2_{20}}$ = 0.13 day^{-1} and

T = temperature, °C.

The ultimate BOD, L, was assumed to be 1.5 times BOD_5.

When Equation (3) is used to perform a mass balance for the bay, L is the average total amount of BOD in the bay on a given day, R_a is the average daily loading of BOD_5, k_2 is a function of the average temperature and k_3 is an unknown. For the summer season (June, July, August), the average BOD_5 concentration (from Figure 21) was estimated to be 2.7 mg/l, making $L = 1.15 \times 10^6$ lb of ultimate BOD; k_2 was adjusted to 23°C (0.147 day^{-1}); R_a was estimated to be 147,410 lb/day; and k_3 was found to be -0.060 day^{-1}. Similarly, for the winter (December, January, February), the average BOD_5 (from Figure 22) was 4.7 mg/l ($L = 2.06 \times 10^6$ lb); k_2 was adjusted to 2°C (0.064 day^{-1}); R_a was estimated to be 122,150 lb/day; and k_3 was found to be -0.024 day^{-1}. The fact that k_3 is negative means that there is a carryover BOD loading from the previous season, probably from the sediments. Wind action is stronger in the summer and will resuspend a higher proportion of BOD; hence k_3 is more important in summer.

With k_2 and k_3 known, it is possible to use Equation (3) to compute a new L associated with a different loading rate R_a. To determine R_a corresponding to each alternative, it was assumed that the percentages of each source of BOD shown in Table 37 were appropriate. The removal of BOD by a combined sewer overflow treatment facility (auxiliary water pollution control facility) for an average storm was assumed to be 57%. A runoff coefficient of 0.65 and an average BOD_5 concentration of 18 mg/l was used to compute the BOD loading due to urban runoff.

Table 37. ASSUMED SEASONAL DISTRIBUTION OF BOD SOURCES

	Percentage of annual (four-season) load, %	
Source	Summer	Winter
Dry-weather flows	25	25
Combined sewer overflows	33	0
Urban runoff	25	25
Marsh grass	25	25

The analysis of Alternatives 1 through 9 was completed by adjusting the rate of BOD_5 input to the bay due to the effects of the combined sewer overflow treatment facilities in each alternative. Alternative 10 required special consideration because it is dependent upon rainfall intensity. An average summer thunderstorm in New York City has a depth of 0.5 in. and a maximum intensity of 1.0 in./hr. By generating synthetic hydrographs for the drainage basins, it was estimated that the interceptor associated with Alternative 10 would capture 46% of the flow from all of the basins during an average storm. The BOD_5 loading to the bay under Alternative 10 was thus based upon 46% removal of the combined sewer overflow source of BOD, all other inputs being the same as for Alternative 3.

URBAN RUNOFF MODEL

Quantity Model

Urban Drainage Basin--

A schematic diagram showing various components of the precipitation-overflow sequence for a typical urban drainage system in which the receiving water is affected by tidal action is presented in Figure 64. The rainfall-runoff relationship has been treated for many years as a linear process. According to linear system theory, the input-output relationship can often be described by the convolution integral:

$$Y(t) = \int_{-\infty}^{+\infty} W(t,\tau)\cdot X(\tau)d\tau \qquad (9)$$

where $X(\tau)$ is the input and $Y(t)$ the resulting output. As the function of the two variables, $W(t,\tau)$ is called the weighting function of the system.

If a linear system is described by a convolution integral, then the output $Y(t)$ at a given time t is a weighted sum of the values of the input over the integral from negative to positive infinity. That is, the contribution to the output from the input is a weighted value of $X(\tau)$, where the weighting is provided by the weighting function $W(t,\tau)$. Applying this to the rainfall-runoff process, a hydrograph can be predicted for any given effective hyetograph if the weighting function is known.

Unit Hydrograph and Instantaneous Unit Hydrograph--

In order to derive the weighting function, it is necessary to introduce the unit hydrograph theory and instantaneous unit hydrograph. The unit hydrograph of a drainage basin is defined as a hydrograph of direct runoff from 1 in. of effective rainfall generated uniformly over the basin area at a uniform rate during a specific period of time or duration. (The word *unit* is often misinterpreted as 1 in. of *unit depth.*) In essence, linearity (superposition) and time invariance are two fundamental principles of the unit hydrograph.

If the duration of the effective precipitation becomes infinitesimally small, the resulting unit hydrograph is called an *instantaneous unit hydrograph* and is expressed by $U(0,t)$ or $U(t)$. By the principle of superposition, when an effective rainfall function $I(\tau)$ of duration t_0 is applied, each infinitesimal element of this effective rainfall hyetograph will produce a direct runoff hydrograph equal to the product of $I(\tau)$ and the instantaneous unit hydrograph expressed by $U(t-\tau)$. Thus, the ordinate of the direct runoff hydrograph at time t is:

$$Q(t) = \int_{t_0}^{t'} U(t-\tau) \cdot I(\tau) d\tau \tag{10}$$

One can easily see that Equation (10) is equivalent to Equation (9). Equation (10) is also known as the Duhamel integral, in which $U(t-\tau)$ is a kernel function, $I(\tau)$ is the input function and $t' = t$ when $t \leq t_0$ and $t' = t_0$ where $t > t_0$.

One important difference between Equation (9) and Equation (10) is that the system described by Equation (9) (usually called a causal or a physically realizable system) cannot anticipate what the future input will be. In other words, the weighting function of a causal system is zero for $\tau > t$; that is, future values of the input are weighted zero.

For a given drainage basin, the ordinate at time t of the unit hydrograph having a unit duration of Δt_0 is presented by $U(\Delta t_0,t)$, where t is any time after the beginning of effective rainfall. The effective rainfall for a given storm may be considered to consist of n blocks of different intensity I_i and of time duration equal to Δt_0 where the subscript i denotes the number representing a block. By the principle of linearity, the ordinate of the direct runoff hydrograph for the given storm may be expressed as:

$$Q(t) = \sum_{i=1}^{n} U \left[\Delta t_0,\ t - (i-1)\Delta t \right] I_i \Delta t \tag{11}$$

Equation (11) is a summation form of the convolution integral, and it describes the principle of computing a direct runoff hydrograph from an effective rainfall hyetograph for each drainage sub-basin. Measured direct runoff hydrographs for each sub-basin from isolated short-duration storms were used to compute unit hydrographs. A basic 20-min unit hydrograph was constructed by averaging several unit hydrographs of 15- to 20-min duration. This basic unit hydrograph has been used to derive direct runoff hydrographs from computed effective rainfall hyetographs.

Determination of Effective Rainfall Hyetograph from Total Rainfall Hyetograph--

In order to determine the effective rainfall hyetograph from the total rainfall hyetograph, the *loss* function for the drainage basin must be formulated. Loss parameters include interception, evaporation, infiltration, depression storage, etc. The relative importance of each loss component depends principally upon the physical characteristics of the land surface.

In most urban areas, for example, rainfall intercepted by vegetation and lost through evaporation during precipitation is rarely of importance. Investigations have shown that infiltration approaches a steady minimum rate after 1 or 2 hr. Infiltration is also affected by antecedent precipitation. High-intensity rains of short duration occurring after a dry spell often produce little, if any, runoff. Depression storage for different land surfaces depends upon their roughness and slope. For the model employed in this investigation, loss parameters are each assigned to a function which generates an effective rainfall hyetograph from any total rainfall hyetograph. Land-use distribution and imperviousness of each surface are the two factors used to estimate the loss parameters. These input values have been adjusted by comparing the computed direct runoff hydrographs with measured direct runoff hydrographs.

Modeling Results and Verification--

The data from several storms were used to prepare input rainfall hyetographs from the unit hydrograph model. Comparisons between the model output direct runoff hydrograph and actual monitoring data are presented in Figure 81, which also shows the input total rainfall hyetograph and the computed direct runoff hydrograph. Note the comparison between the computed and measured values at the Spring Creek East monitoring site. Discrepancies arise from the following.

1. The computed values were based on the assumption that the dry-weather flow (base flow) follows the pattern of the average condition. However, for any given day, this value may be affected by the operation of water pollution control facilities, which may alter the initial amount of conduit storage.

2. Monitored overflows were affected by the existence of two tide gates located approximately 800 ft downstream of the Spring Creek East diversion chamber. These gates were removed during construction of the Spring Creek Auxiliary Water Pollution Control Facility.

3. At the monitoring site, two sets of temporary weir structures were used for metering. These weirs created some storage in the lower reach of the conduit system but will be removed at the plant's completion. The effects can be seen in the measured hydrograph. For example, the model predicts a smoother initial hydrograph than the measured values, which show a few minutes of delay and a much sharper slope, caused by the presence of the weirs. One may also note that the combined hydrograph predicted at the plant intake during the whole overflow process receives the overflow from the Spring Creek West drainage basin earlier than that from the Spring Creek East basin. The time lag is approximately 10 min in this case because the mointoring point for Spring Creek East was approximately 8,000 ft from the plant intake. (The main body of the flood wave, which is kinetic in nature, travels at a speed of approximately 1.5 times the flow velocity.)

4. Although the precipitation data were obtained from instruments in the drainage area, it is probable that the indicated amounts of rainfall did not fall uniformly over the entire tributary area.

Figure 81 shows the inflow hydrograph to the plant and the downstream level at Spring Creek. The figure also shows the basin's water level, the average apparent velocity in the basin and the flow-through velocity. These hydraulic parameters will enter the prediction model as input quantities. At present, the storage-level relationship of the whole system is only approximate.

Quality Model

Combined Sewer Overflow Coliform Pollutographs--

In the study of the rainfall-runoff relationship it is usually assumed

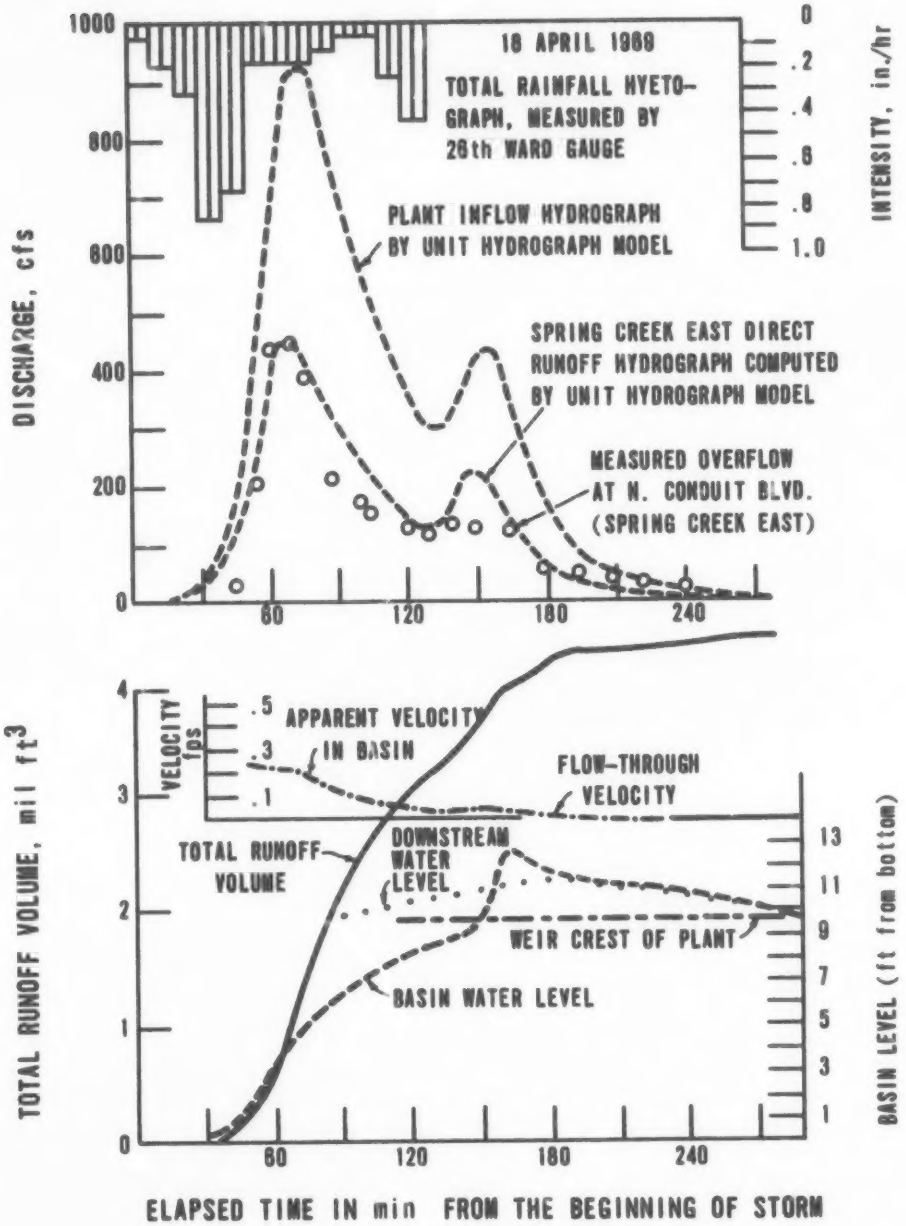


Figure 81. Comparison between the computed and the measured overflow from Spring Creek drainage basin

that an urban drainage basin is essentially a linear system. This implies that the response of the system is linearly proportional to the *effective* inputs and can be estimated with the use of a transfer function. An extension of this methodology can be quite useful in the analysis of storm pollutographs. However, the analogy should be approached with extreme caution when dealing with pollutographs because the system has certain *memory*.

For any particular instance during an overflow, the amount and concentration of coliform bacteria are the combined results of the following processes:

1. Coliforms contained in the dry-weather flow are being mixed and diluted by the stormwater. At any given time, t, the resulting coliform concentration is equal to the product of the dry-weather concentration and flow rate divided by the sum of the dry- and wet-weather flow rates as shown below:

$$C'_t = \frac{C_{D(t)}\ q_{D(t)}}{q_{D(t)} + q_{S(t)}} \tag{12}$$

where C_D = dry-weather coliform concentration;

q_D = dry-weather flow rate; and

q_S = wet-weather flow rate.

C'_t is the concentration component which is caused by dilution alone. The characteristic shape of C'_t is an inverted Gaussian curve (skewness and peakedness depend upon the storm hydrograph) with each end asymptotically approaching the dry-weather concentration.

2. The second contributing component is derived from bottom scouring. The amount of contribution depends greatly on the *memory* of the sewer system. This effect is more pronounced when the sewer system has a low elevation and is equipped with tide gates. If a storm begins during a high-tide condition, the ponding effect will cause a major portion of the solids to settle out in the trunk sewers. This prolonged tidal recession and dewatering process will not have the ability to carry away the settled solids and bacteria. Qualitatively speaking, the coliform concentration contributed by this process is proportional to the scouring velocity and limited by the concentration available. The amount of scouring is proportional to the n^th^ power of the flow. Therefore, the concentration contributed from the scouring action is:

$$C''_t = \alpha S(q_S + q_D)_t^{n-1} \tag{13}$$

where S = coefficient which is a function of storage factor and sewer slope;

$\alpha = 1$ when $t \leq t_{max}$ or

$\alpha = 0$ when $t > t_{max}$';

t_{max} = time of hydrograph peak; and

n = empirical coefficient.

The characteristic shape of the concentration curve from this component rises exponentially as the storm hydrograph rises but drops sharply when the available concentration is exhausted.

3. Another important source of coliforms is the street gutters. The amount contributed from street gutters is highly variable due to the different street cleaning frequencies, pet populations and antecedent dry periods involved. The graph of the amount contributed from this source has the same shape as the overflow hydrograph due to the early impact of the storm causing most of the pollutants in the street gutters to be carried to the sewer system. The curve is proportional to the k^th^ power of the hydrograph resulting from the first few effective storm impulses (first 10 to 20 min) divided by the first power of the hydrograph itself, as shown below:

$$C_t''' = W \frac{(q_S)_t^k}{(q_S)_t} = W(q_S)^{k-1} \qquad (14)$$

where $(q_S)_t$ = ordinate of the storm hydrograph at time t;

W = coefficient varying with street cleaning frequency, basin geometry and population density; and

k = coefficient varying from 1.5 to 2.0.

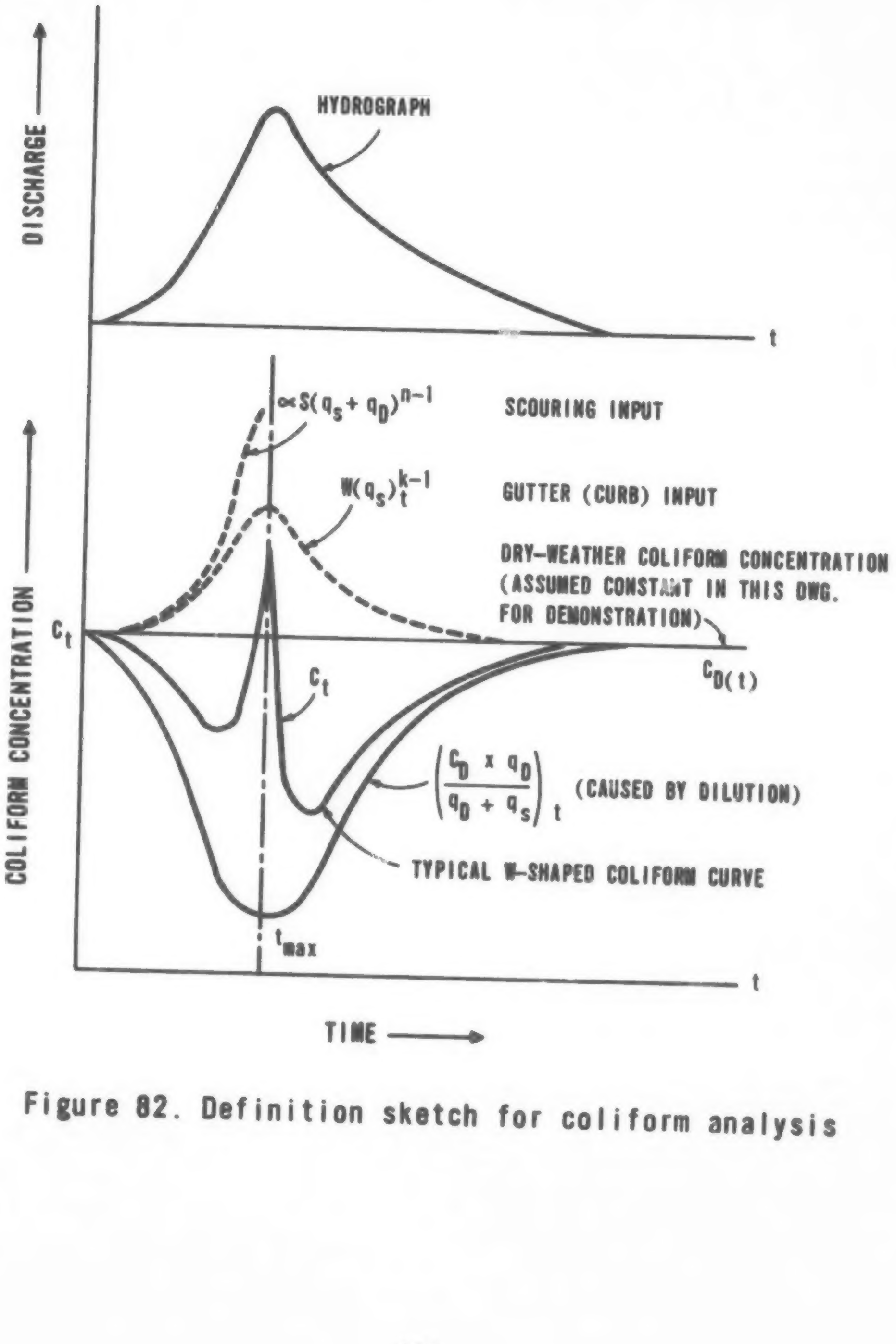
Combining the effects of dilution (Equation (12)), scouring (Equation (13)) and street gutters (Equation (14)) yields:

$$C_t = C_t' + C_t'' + C_t''' = \left[\frac{C_D q_D}{q_D + q_S}\right]_t + \alpha S(q_S + q_D)_t^{n-1} + W(q_S)_t^{k-1} \qquad (1)$$

For a typical storm, the time history of coliform concentration, C_t, will exhibit the W-shaped curve shown in Figure 82. Coliform data taken at the five combined sewer overflow monitoring sites have confirmed this configuration.

Comparison Between the Computed and Observed Coliform Pollutographs--

Through physical reasoning, each component of the coliform pollutograph has been identified. This section deals with estimating the coefficients and with comparisons of the computed and measured values.



DISCHARGE
HYDROGRAPH
t
COLIFORM CONCENTRATION
$\propto S(q_s + q_D)^{n-1}$
SCOURING INPUT
$W(q_s)_t^{k-1}$
GUTTER (CURB) INPUT
DRY-WEATHER COLIFORM CONCENTRATION (ASSUMED CONSTANT IN THIS DWG. FOR DEMONSTRATION)
C_t
C_t
$C_{D(t)}$
$\left(\frac{C_D \times q_D}{q_D + q_s}\right)_t$ (CAUSED BY DILUTION)
TYPICAL W-SHAPED COLIFORM CURVE
t_{max}
t
TIME

Figure 82. Definition sketch for coliform analysis

An approximation of the powers in Equation (1) has been made from close scrutiny of the measured coliform concentration curves. For all the drainage systems monitored, n is approximately equal to 3.0 and k is approximately equal to 2.0. Coefficients S and W vary with the drainage system because of the basin and sewer network characteristics.

On 3 July 1969 a storm was monitored at both Spring Creek East and Spring Creek West basins. This storm and a storm occurring on 2 February 1970 monitored at Hendrix were used to derive the values of S and W for each basin.

The dry-weather flow coliform concentrations for each drainage area were assumed to be as follows:

North Conduit	1.0×10^6 MPN/ml
Spring Creek Basin	2.0×10^6 MPN/ml
Thurston Basin	1.0×10^6 MPN/ml
Hendrix Basin	1.0×10^6 MPN/ml

These values were derived from the initial and final values on the monitored coliform curves.

An example of the comparisons between the computed and observed values of coliform concentration along with approximations of S and W yielding the *best fit* curves is presented in Figures 83 and 84 for the Spring Creek East and Spring Creek West basins. Upper and lower 95% confidence limits of coliform densities were computed for each observed MPN value and are shown on each graph.

In comparing the computed curve with the measured curve, it should be remembered that points identified on the measured curve do not necessarily reflect turning points of the true coliform distribution. Periodic sampling produces the discontinuities shown, but the short time between samples decreases the possibilities of the true curve being much different from the measured curve. In addition, the values of S and W will vary slightly for each discrete storm in a given drainage basin. However, the magnitude of the coefficients will not change the basic shape of the computed curve. Furthermore, the relative influence of the powers, n and k, on the shape and magnitude of the curve is much greater than that caused by S and W. These powers have been found to be the same for all monitored drainage basins.

All computed curves agree quite well with the observed values. Using $S = 10$ and $W = 100$ for the Spring Creek East basin, the agreement is excellent. In the case of Thurston Basin, the values of $S = 3$ and $W = 0$ produced close agreement. In Hendrix Creek, $S = 20$ and $W = 10$ yielded desirable results, and in Spring Creek West good results were achieved with $S = 50$ and $W = 1,000$.

Higher S values were indicative of pronounced scouring effects, and high W values indicated large contributions from surface washing. The rela-

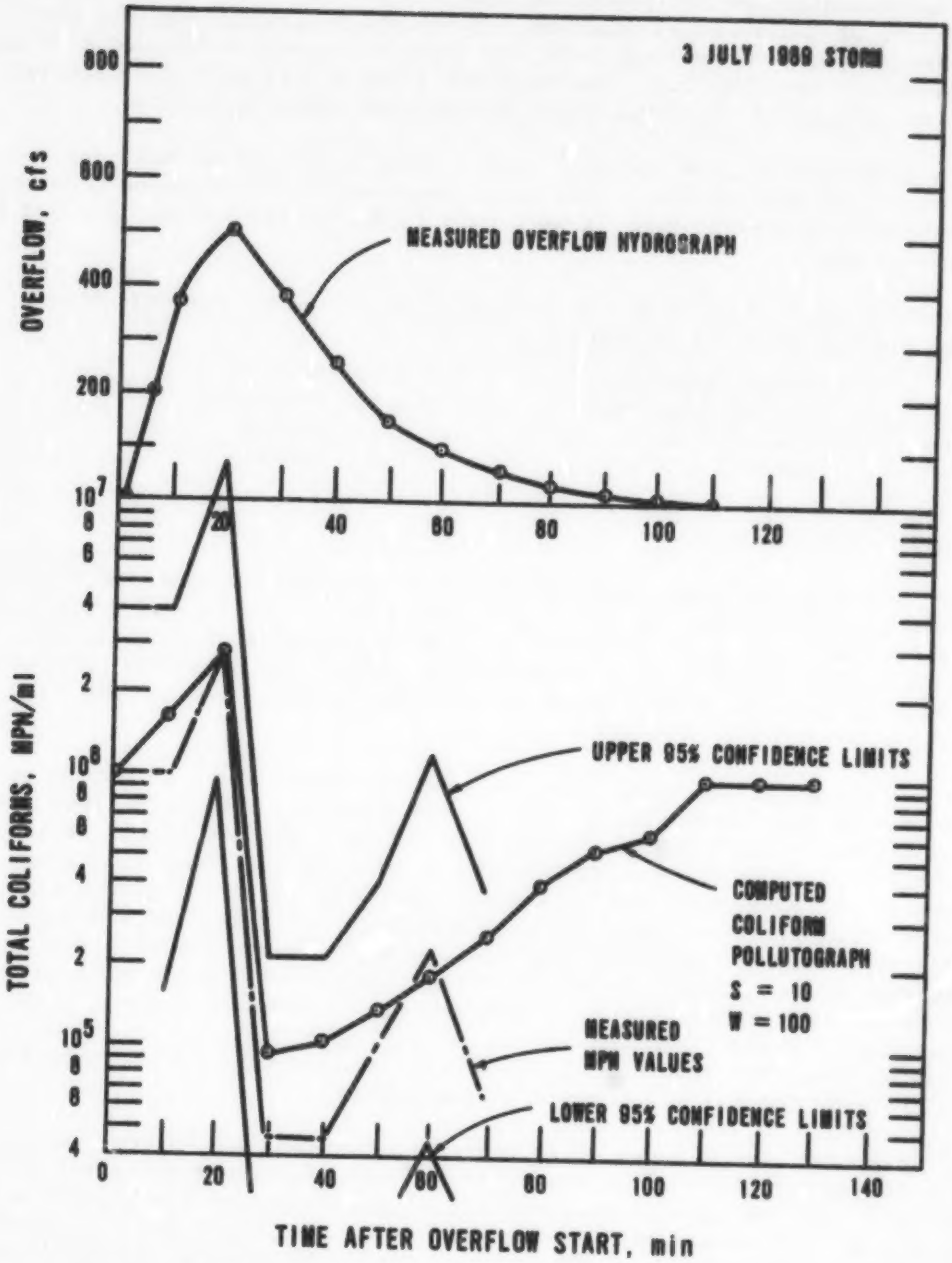


Figure 83. Comparison between the computed and the measured coliform pollutograph, Spring Creek East drainage basin

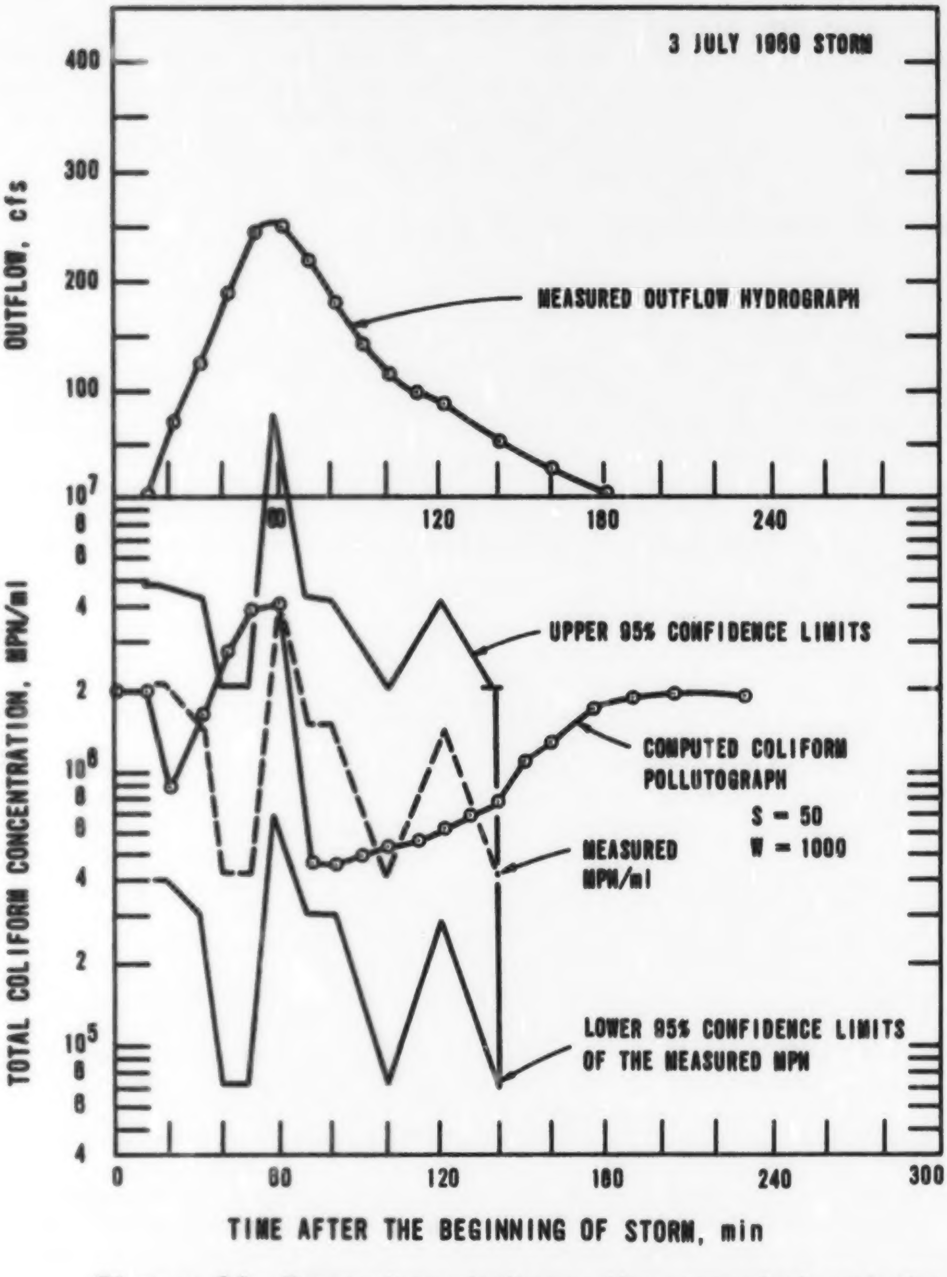


Figure 84. Comparison between the computed and the measured coliform pollutograph, Spring Creek West drainage basin

tively high S value of Spring Creek West is caused by the low sewer elevations, which result in ponding and subsequent scouring of large amounts of pollutants. The flat land surface effects the size of W for Spring Creek East. With these constants evaluated, and with knowledge of their relationship to sewer and surface characteristics, estimates for other areas become relatively easy. In addition, a minor amount of monitoring (two or three periods) of a system will permit excellent evaluation of these parameters.

RAND TWO-DIMENSIONAL WATER QUALITY MODEL

Methodology

The study of technical solutions to the problem of wastewater management in an estuary involves complicated relationships such as those among waste loading, location of discharges, degree of treatment, geometry of the estuary, flow in the estuary and temperature. Models can be built to predict the probable consequences of each of the alternative solutions chosen. Using the predictions obtained from these models and whatever other information or insight is relevant, alternatives can be compared and conclusions drawn concerning the most desirable course of action.

The Rand two-dimensional water quality simulation model, schematically shown in Figure 85, is based on the numerical solution of the two-dimensional vertically integrated equations of motion and continuity for a fluid. First, the water velocities and levels are computed taking into account the variation of the area and shape of the bay due to rise and fall of the tides. The transport of constituents in the waters of the bay is then determined using the computed velocities and levels. In addition, the different constituents of the fluid wastes can react with each other or with natural substances in the water; thus a reaction model describing these biological and chemical processes, as well as their interactions, is included. At present, this model computes the concentrations of six soluble constituents simultaneously.

The two-dimensional bay water quality model is linked to an urban runoff model similar to the one described in the foregoing section except for the basic mechanism for determining the predictive kernel function. The cross-spectral method is employed in the Rand version.

Input/Output

An extensive computer program was developed to solve the momentum and continuity equations of fluid flow, along with constituent mass-balance equations, to obtain the time and space distributions of waste constituents in bays or estuaries. Since the problem is time-dependent and attempts to simulate real-world conditions, large numbers of input data describing the characteristics of the area to be studied are required. In addition, the results of the computation can be presented at every

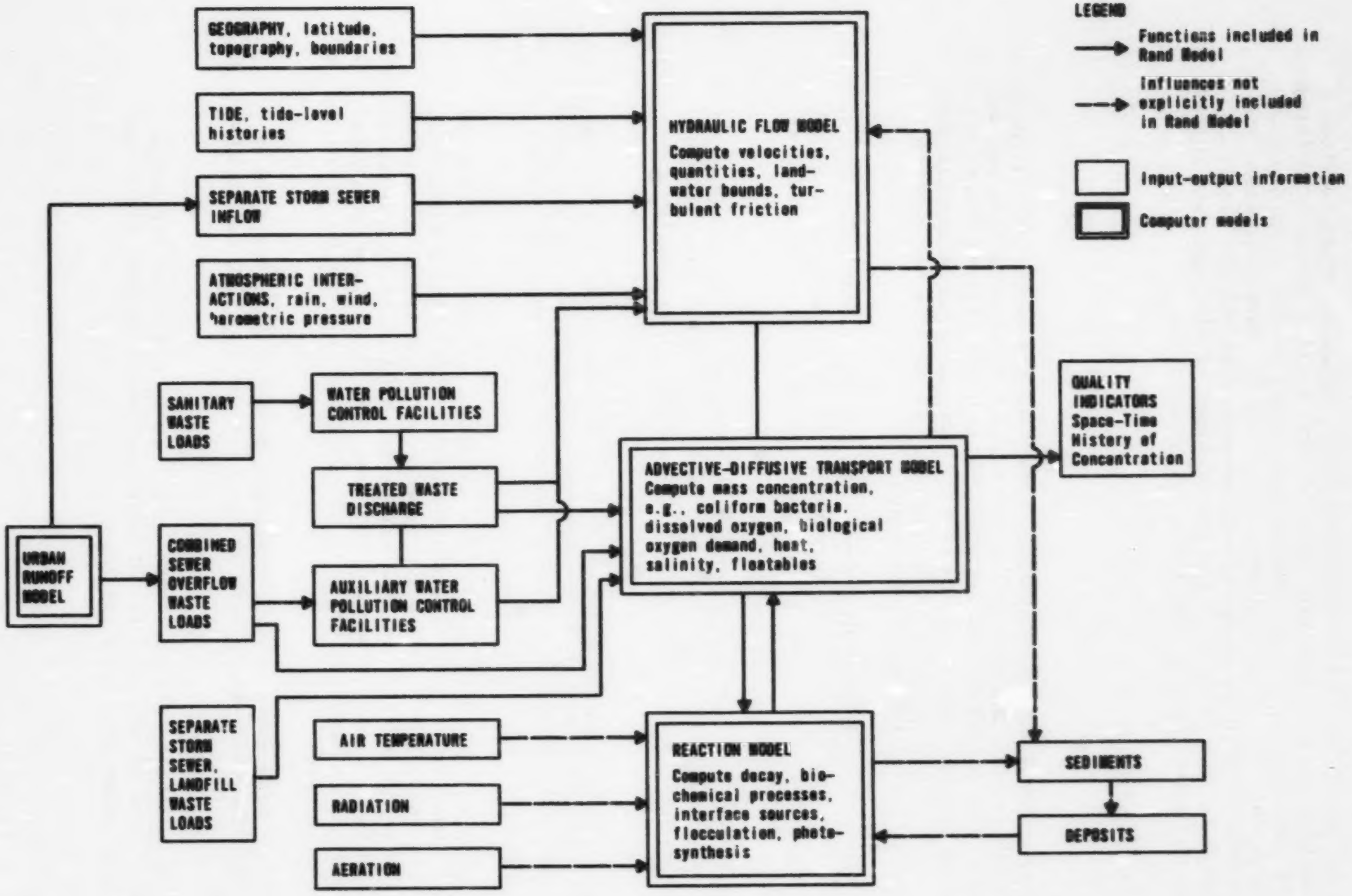

GEOGRAPHY, latitude, topography, boundaries
TIDE, tide-level histories
SEPARATE STORM SEWER INFLOW
ATMOSPHERIC INTER-ACTIONS, rain, wind, barometric pressure
SANITARY WASTE LOADS
WATER POLLUTION CONTROL FACILITIES
TREATED WASTE DISCHARGE
URBAN RUNOFF MODEL
COMBINED SEWER OVERFLOW WASTE LOADS
AUXILIARY WATER POLLUTION CONTROL FACILITIES
SEPARATE STORM SEWER, LANDFILL WASTE LOADS
AIR TEMPERATURE
RADIATION
AERATION
HYDRAULIC FLOW MODEL
Compute velocities, quantities, land-water bounds, turbulent friction
ADVECTIVE-DIFFUSIVE TRANSPORT MODEL
Compute mass concentration, e.g., coliform bacteria, dissolved oxygen, biological oxygen demand, heat, salinity, floatables
REACTION MODEL
Compute decay, biochemical processes, interface sources, flocculation, photosynthesis
QUALITY INDICATORS
Space-Time History of Concentration
SEDIMENTS
DEPOSITS
LEGEND
Functions included in Rand Model
Influences not explicitly included in Rand Model
Input-output information
Computer models

Figure 85. Input-output and components of Rand water quality simulation model (after [9])

grid point and at each succeeding time step. However, interpretation and extraction of important results from such a large volume of printed numerical data rapidly becomes impossible. Thus several routines using interactive computer technology were developed for data insertion, and programs were written to generate machine-made drawings for graphical presentation of the results of the computation. These input and output procedures are described in the following subsections.

Hydraulic Flow Model

Inputs--

Bathymetry. Depth data or elevation above mean sea level (values for h) are input at each grid point within the field. For the Jamaica Bay model, a grid size of 500 ft was selected, which gives rise to a data array of 78 by 61 points. One array is used for the depth and elevation data, and this information is read in from cards. If no data are inserted at a particular grid point, land is assumed.

Determination of Land-Water Boundary. The boundary location is dependent upon the tide stage and is thus time-varying. One data array is used to store the water level that remains on the tidal-flat areas as they become dry.

Open Boundaries. At the open boundary, a time history of the water level is given as a function of the input tide. The input water levels are given at every third time step, with a linear interpolation used between.

Latitude. The latitude is given in degrees of the center of the area of computation. The effect of a variation in the Coriolis acceleration over the area of a very large body of water is not simulated in the present program.

Manning Value and/or Chezy Value. The investigator has the option of defining a Chezy value over the entire field or computing periodically a value from Manning's n (which is variable over the field) as a function of the water level. Two data arrays are used to store the appropriate Manning's n input value and the time- and space-dependent Chezy coefficient. If a specific value is not inserted or computed, a default value is used.

Meteorology. Wind speed and direction are inserted as a function of time so that the wind-stress term in the momentum equation can be determined.

Location of Discharge Points. Time histories of the fluid discharges at the locations of the outfalls of water pollution control facilities and combined sewer overflows are input.

A total of 16 wastewater inputs into the model are used, as listed below:

1. 26th Ward Water Pollution Control Facility effluent
2. Jamaica Water Pollution Control Facility effluent
3. Rockaway Water Pollution Control Facility effluent
4. Hendrix combined sewer overflow
5. Thurston combined sewer overflow
6. Bergen combined sewer overflow
7. Paerdegat combined sewer overflow
8. Fresh Creek combined sewer overflow
9. Rockaway combined sewer overflow
10. Bergen separate stormwater overflow and surface runoff from the west portion of John F. Kennedy International Airport, which discharges at the end of Bergen Basin
11. Thurston separate stormwater overflow and surface runoff from the east portion of John F. Kennedy International Airport, which discharges at the end of Thurston Basin
12. Mill Basin separate stormwater overflow
13. Runoff from the Fountain Avenue landfill
14. Runoff from the Rockaway landfill
15. Broad Channel East combined sewer overflow
16. Broad Channel West combined sewer overflow

Outputs--

Velocities and Water Levels. Four types of output presenting velocity and water-level data can be obtained from the simulation model.

1. Graphs--Graphic output giving velocity vectors and water levels at selected points and times can be made on film or as hard copy. The graphic output displays the outline of the bay at the approximate location of the high-water line and the grid points at which the water levels and constituent mass densities are computed. As the water level in the marshy areas changes with time, the number of points in the computation varies since some areas become dry while others flood. Velocity vectors are computed at the locations of the water levels from the average of the surrounding velocity components. These vectors are plotted at every second grid point in orthogonal directions. Water levels are printed out at selected locations in the bay. The locations of the outfalls of sewage treatment plants, combined sewer overflows and stormwater runoff locations are shown on the output. The graphic output can be obtained at any interval desired. Normally, records are made every 1 or 2 hr of real time. If the graphs are printed at each

time step, a motion picture can be made showing the time variation of the velocity vectors over the area of the bay.

2. Numerical velocity and water-level data--Printed numerical data of the water levels and the velocity components at each point on the grid can be obtained at selected time intervals. Again, these data are usually printed out every 1 or 2 hr of real time.

3. Velocity and water-level time histories--The velocities and water levels at selected points in the bay are graphed as a function of time.

4. Water-level field information at specific times--It is possible to obtain water-level isocontours of the water-level information in graphical form. In addition, a three-dimensional view of the water levels can be produced using a computer-graphics system.

Advective-Diffusive Transport Model

Inputs--(except those generated by the flow model)

Constituent Time Histories at Open Boundaries. The concentration of each of the constituents is described as a function of time at the open boundaries of the model.

Concentration of Constituents in Discharges. The concentration of each of the modeled constituents in the wastewater discharges from the outfalls of the dry-weather sewage treatment facilities, combined sewer overflows and other inflows is input as a function of time.

Dispersion Coefficients. The dispersion coefficient is composed of several terms. First, a term dependent on lateral dispersion is input at every point in the field. If it is not specified at a particular point, a default value is used. A second term is then computed as a function of the velocity component, depth and Chezy coefficient so that the total coefficient is time-varying.

Initial Constituent Concentrations throughout the Field. At the beginning of the computation, initial values of the constituent concentrations at each grid point are input. If these values are not given, a specified default value is used.

Outputs--

Graphs. The mass densities of the constituents are plotted on graphs by means of isocontour lines. These graphical data are generally combined with the output of the flow model as described previously. Numerical values of the constituent concentration are printed out at selected locations in the field, and the values of the adjacent isocontour lines can be obtained by extrapolation.

In the Jamaica Bay study, four constituents are computed simultaneously: dissolved oxygen, biochemical oxygen demand, salinity and coliform bacteria from three independent groups of sources. Twelve data arrays are used in the calculation of the constituents because of the two time levels involved.

Numerical Values of Constituent Concentrations. Printed numerical data of concentrations of each of the constituents are obtained at each grid point. This information and the numerical velocity and water-level data are printed out at the same time.

Time Histories of Constituent Concentrations. The concentrations of the various constituents are graphed as a function of time at selected grid points in the bay. These data can then be compared with field measurements to ensure correct adjustment of the model. If necessary, these data can be smoothed as well.

Reaction Model

Inputs--

Disappearance Rates. The first-order disappearance constants for the coliform bacteria must be input. These values are determined experimentally from field measurements.

First-Order Reaction Rates. The reaction coefficient in the BOD-dissolved oxygen reaction model is estimated from field measurements, and adjustments are then made to correctly simulate field data.

Source-Sink Function. In the present model, this includes the reaeration coefficient of oxygen. This input value can currently be varied over the area of the computation. Various equations are available to aid the model user in estimating an appropriate reaeration coefficient.

Output--

The reaction model feeds information to the advective-diffusive transport model and has no separate set of unique outputs.

Calibration

Hydraulic Flow Model--

The hydraulic flow model has been adjusted to obtain a good fit between observed and computed tidal amplitude data. Particular emphasis was placed upon the tidal phase throughout the bay because of its effect upon water circulation. The flow model is adjusted by changing the value of Manning's n, which in turn leads to a change in the computed Chezy coefficient. The latter is used in the computation of the dispersion coefficient in the advective-diffusive transport model.

Advective-Diffusive Transport Model--

For the evaluation of the two-dimensional bay model, together with the urban runoff models, the distributions of coliform bacteria in the bay resulting from a rainstorm in the period 31 May to 2 June 1972 were sampled by the Department of Water Resources, City of New York. Water quality simulations were also made for the same event with the two-dimensional model. Reasonable agreement between observed and computed coliform densities was obtained. Further calibration and verification work is planned, including simulation of additional water quality parameters.

Water Quality Management Applications of the Model

The two-dimensional water quality simulation model is designed to give predictive capability on the hydraulic and water quality responsive behavior of the bay system under various engineering alternatives. Stochastic models can be developed to assess system parameters for the water quality simulation model and also to derive water quality transfer functions for real-time prediction in conjunction with the urban runoff models. Once the water quality transfer functions from rainfall to bay water quality are determined, simulation with the two-dimensional water quality model is no longer required.

Stochastic models can also be used for determining the process equations for the treatment process in the combined sewer overflow treatment facilities from observed data, and these models will be the basis for real-time prediction of flow rates and incoming water quality at the auxiliary facilities. It may be appropriate for the transfer functions to be stored in a small process-control computer in the auxiliary facilities to determine the required control policy (e.g., chemical dosing) according to real-time information from rain gauges and tide gauges.